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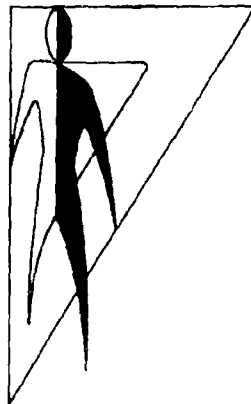
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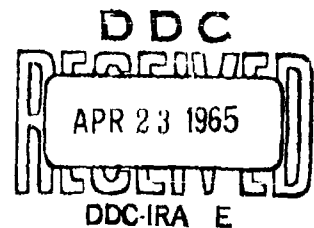
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RADAR SYMBOLOGY:  
A LITERATURE REVIEW

Alfreda R. Honigfeld

September 1964  
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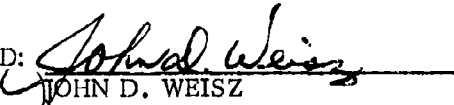
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RADAR SYMBOLOGY:  
A LITERATURE REVIEW

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September 1964

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## ABSTRACT

This literature review was undertaken to summarize the state of the art of symbology in radar display systems. It reviews the various techniques for coding, extracts general principles for use in designing radar systems, and recommends areas for further research.

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## **RADAR SYMBOLOGY:**

### **A LITERATURE REVIEW**

#### **INTRODUCTION**

The purpose of this literature review was to determine whether prior research in radar-display symbology and coding techniques would support a standardization program. The result of this review would then be a standard set of symbols, with attendant meanings, for application to future radar-display-system designs.

The need for a standard symbology is highlighted by the fact that each contractor who develops a radar system has, in the past, been allowed to arbitrarily select a symbol code and its meaning for display use. Since symbols have not been specified formally, the result is a unique code for each system. Symbol meanings differ from system to system: identical meanings might be represented on one display by numbers, on another by letters, and on a third by geometric forms.

As the variety of systems increases and obsolete systems are phased out, personnel are taken from one system, retrained, and reassigned to new systems. The vast literature on human learning shows the interference and inefficiency which results from conflicting habits. Habit interference is particularly disrupting when familiar stimuli require a new set of responses in a new task. This inefficiency is enhanced under stress conditions, where people revert to earlier experience and respond as they did in previous situations. In the often stressful atmosphere of radar operation, an operator may revert to his old mode of response and designate an enemy as a friend or vice versa. This possibility necessitates the standardization of radar-display codes.

Bergum and Burrell (1964) attempted to determine the extent to which symbols are confused when an individual who has learned a second set of symbols involving either new symbols or old symbols with new meanings views these symbols under conditions of stress. Their results showed significant interference in going from one symbology to another when the same symbols with new meanings were used. Moreover, the evidence indicated a high level of confusion between pairs of symbols used in present radar systems. It thus appears that, even without any interference from new learning, present symbologies are a potential source of human error when viewed under stress.

In format, this paper begins with a review of the principles of form perception. This was felt necessary since a rudimentary understanding of the theory of visual perception would seem basic to the development of a practical symbol system. This section is followed by an outline of the problems confronting a radar operator and the tasks he must assume.

The main body of this paper deals with the principles of symbolic coding for visual displays, the methods of coding, a review of the studies in each code area, and samples of different codes. In a practical situation it is rare that a single code symbol is used alone. Instead, a numeral might be combined with a geometric form, or a form might be colored or flickered, etc. But for clear exposition of the information contained in this report, it was decided to analyze each code system as a separate entity. (Summaries of coding methods, sizes for visual elements, rank orders of geometric symbols, and the studies reviewed will be found among the appendixes.)

This paper concludes with recommendations for developing coding systems and suggestions for further study.

There are numerous reports of only tangential pertinence to this review. While these reports are not discussed in the body of the paper, they are included in the bibliography.

## FORM PERCEPTION

The quality of an object that remains invariant under changes in its size, place, material, and time is commonly called the object's shape. The correlated sensory or perceptual experience whose invariance matches that of the shape of an object is "form perception." When more than one shape is involved, "patterns" result.

Gestalt theory utilizes the "Law of Prägnanz" which refers to the way an entire visual field is differentiated and organized perceptually into "figure" and "ground." It gives "figural goodness" as the goal of perception. "Good" shapes and patterns are generally described as having few parts and being homogeneous, regular, symmetrical or, in short, "simple." What the object's shape lacks in "goodness" may be added by the observer in perceiving its form.

A list of the Gestalt theories on which the perception of characteristic patterns is based follows.

### Predominance of Figure over Ground

Compared to the ground, the figure is more predominant and impressive. Every figure has "form quality"; the ground as such is shapeless. If the ground assumes form, it becomes a figure in its own right.

### Significance of Contours

Contours are not merely dividing lines between figure and ground; they also have formative functions for the figure.

## Integrity and Size

Whenever one of two contrasting but otherwise homogeneous fields is markedly larger and encircles the smaller one, the small (surrounded) field will be seen as figure, while the larger (surrounding) field will be seen as ground.

## Simplicity

Forms are more apt to be perceived as figure if they are simple, rather than complex. Of two intersecting or super-imposed forms, the simpler one has the better chance of being considered the figure.

## Symmetry

Symmetry of an object or field and its symmetrical arrangement favors its perception as a figure.

## Similarity of Color and Shape

Similarity of color and form elements favor the perception of a figure. The more difference there is between the color and form elements, the more difficult it is to combine them into a figure. Strong similarities dominate over smaller differences of color and form and make figuration possible.

## Similarity of Behavior

Various objects which act in a similar manner are grouped by the act of perception and assume figure quality in our consciousness. Moving objects are seen more easily against a stationary background than objects at rest. Larger objects which are otherwise invisible because of minimal brightness contrast may become discernible when in motion within their surroundings.

According to Gestalt theory the simpler the visual shape or pattern, the easier it is for man to perceive form. The greater the number of visual parts, the more inaccurate the report. Also, the less regular and symmetrical the shape of the visual stimulus, the less accurate and rapid the form perception. The "simpler" the shape or pattern -- the more likely people are to transmit or perceive it accurately and rapidly. When distortions do occur, they are likely to be in the direction of losing information and reproducing a "simpler" figure.

Fehrer (1935) found that simple symmetrical shapes are most easily learned. Woodworth and Schlosberg (1954) emphasized the virtues of symmetry. Fitts et al. (1956) found that figures symmetrical around a vertical axis led to somewhat better performance than those symmetrical about a horizontal axis. Attneave (1957) found that observers rate simplicity of shape chiefly from the number of turns in the contour and their symmetry and sharpness. Dardano and Donley (1958) and Dardano and Stephens (1958) studied a limited range of shapes on radar screens and found complete figures like circles more discriminable than semicircles.

Gaito (1959) found that the tendency to perceive a curved line as straight was much greater than the reverse. Thus it is easier to perceive a straight line accurately than to perceive a curved line accurately. He also found that a single curved line is more easily perceived than two or three straight-line forms.

According to Alluisi's (1960) literature survey, Weinstein (1955) and Anderson and Leonard (1958) found that complex figures took longer to identify.

But another literature review, by Bowen et al. (1959), concluded there is no general agreement about which shapes or shape properties are easiest to recognize. Early work in the field stemmed from an interest in the Gestalt definition of "good" figure and the hypothesis that the circle is the most primitive and dominant shape. However, a number of papers (Collier, 1931; Whitmer, 1933; King et al. 1944; Casperson, 1950; Smith and Boyes, 1957) demonstrated that the triangle, rectangle, or cross can still be perceived after the circle has become sub-threshold. Braly (1933) emphasized the role of past experience and familiarity when recognizing shapes.

Rappaport (1957) did not verify his hypothesis that symmetrical figures would result in better performances than equally complex asymmetrical figures.

Deese (1960) found that when observers need only remember one form at a time, complex forms (made of abrupt, right-angled changes in contour) are more accurately identified than simple forms, in immediate recognition tests. But when observers must remember ten to 25 forms, simple forms are more accurately identified. In this study it was suggested that when observers verbally label or code forms, the relationship between complexity and recognition disappears. Deese concluded that "unique" forms which present relatively large amounts of information are more discriminable and easier to identify but, because they contain more information, are harder to remember.

Gestalt principles of perception would appear to have limited usefulness in developing radar symbology. Such concepts as simplicity of form and symmetry have received only mixed support in symbology research. While there are a number of parameters for constructing distinctive shapes, there are no general rules, since a shape's recognition value is only partly dependent on its geometric construction. The recognition value of a form is also dependent on its similarity to other forms being used, the number of other forms, and the observer's familiarity with it.

## RADAR OPERATION

The Advanced Visual Information Display (AVID) report published in 1961 lists the essential decisions required of a radar operator as detection, threat identification, target selection, commitment, and evaluation. Other, less demanding decisions are also required; normal chain-of-command status reports and orders must be received, evaluated, and issued in exchanges with the designated commands. The varied and complex responsibilities an operator has in the battlefield environment are further complicated by the enemy's attempts to deny information, to introduce confusion in the information, and to saturate information-handling capacity. And finally, from the information available, the operator must make effective and precise decisions in a minimum of time if his unit is to be of any value. Man's basic role in a radar system is detecting targets, processing information, and initiating appropriate command actions. His ultimate performance depends on the interaction of a number of factors. Significant factors influencing the detection of target data are:

a. Area Searched. Generally, detection time increases with the area that must be examined. The effectiveness of search can be increased by reducing spatial uncertainty; this may be achieved by assigning more than one operator to perform a sector search.

b. Target Discrimination. This is a function of factors such as relative motion, brightness, size, symbol type, viewing distance, and target-background contrast. Generally, a target becomes more difficult to see as its size becomes smaller, its trace becomes dimmer, its form becomes less distinct, or its viewing distance becomes greater.

c. Irrelevant Information. Search time and errors increase in relation to the amount of irrelevant information on the display.



d. **Frequency of Occurrence.** Human vigilance efficiency deteriorates quickly, particularly when targets appear infrequently and the time on duty increases. The major decrement occurs during the second half hour of a watch. Vigilance is an important consideration in display design, especially where high levels of attention are required or where critical judgments are required of decision-makers, who should not be expected to maintain long watches. Techniques such as artificial target inputs, frequent rest periods, and the use of multiple sense modalities can be applied to increase vigilance performance.

e. **Information Processing.** The primary concern here is the amount and kinds of information man can deal with best. Ability to process information depends on factors such as:

(1) **Automation.** Computers can be used to decrease the complexity of information presentation and increase man's capability of making the major and significant decisions.

(2) **Amount of Information.** The greater the number of information bits that must be handled in a unit of time, the greater the chance of error. As information becomes more complex, causing the man to perform more operations, it markedly decreases his ability to perform effectively.

(3) **Temporal Characteristics.** Time compression or expansion techniques can be used to increase man's ability to comprehend slowly or rapidly changing situations. Factors which must be considered when information is presented sequentially are:

(a) **Rate at which display changes.** It has been shown that a presentation time of 0.07 second is nearly as efficient as 5.0 seconds when the task (perception of forms) requires only a glance and does not require extended viewing time.

(b) **As the interval between presentation of events approaches zero, the too-rapid presentation may cause human error.**

(c) **Positive or negative afterimages resulting from visual stimulation can influence the perception of a succeeding event. A negative afterimage of color will produce a complementary hue, while a positive image will produce an afterimage the same color as the stimulus.**

(d) **Successive visual stimuli that are close together can result in apparent movement or Phi phenomenon, i.e., perceiving movement between two objects even though neither object moves.**

(e) **Flashing lights can be made to appear as one as a function of rate and intensity of flash.**

(4) Spatial Characteristics. The pictorial display should represent a familiar approximation to the real situation. Elements should not be concentrated so much that crowding and interference effects become a problem. Displays should concentrate on providing interpretable recent information. The farther ahead the man must predict, the more poorly he will perform. Past target information is not necessary in many tasks.

(5) Psychological Stress. Three types of stress on a human can be considered. One results from increased speed and complexity of the task; another is emotional in nature. (Emotional stress results when the man perceives that outcomes of impending events may have serious implications for him.) The physical environment can also present stressful conditions in the form of heat, humidity, air pressure, acceleration, movement, odors, etc. Stress usually produces some deterioration in performance and regression to more familiar modes of response. However, overlearning can reduce some of the deleterious effects of stress.

## METHODS OF CODING

### Basic Principles in Symbolic Coding for Visual Displays

Muller et al. (1955), in an extensive project, have developed basic principles of coding information symbolically for cathode-ray displays and for projection or map-type displays. Symbolic coding makes information available immediately; there is no lag as when interpreting oral and/or written directions. Thus symbolic coding should reduce the operator's memory load, improving his efficiency and reducing accidents due to forgetting or fatigue. Symbolic coding should free communication channels from repeatedly transmitting information, thus allowing more time for precise, detailed instructions. Symbolically coded targets should give the operator a better picture of the total situation, allowing for better plans and organization.

The Recommendations section lists the basic principles to follow in selecting a symbolic code.

Another factor that should be considered in displaying codes visually is brightness of signal marks. Within limits, bright signal marks will be seen more readily than dim marks; images which differ from their background in brightness and form are detected more readily than those which are similar to their background. Also, large marks can be seen more readily than small ones.

Bartlett and Williams (1947) made a preliminary study of how the size of cathode-ray-tube (CRT) symbols affects their visibility. Their smallest image subtended one minute by 12 degrees of visual angle at a viewing distance of 12 inches. It was found that very dim targets could be discriminated more readily if the eyes were near the scope face (six inches) than if they were farther away (24 inches). While this finding held true for dark or moderately bright CRT backgrounds, it did not apply when there was noise (random brightness variations). Detecting targets from a noise background involves pattern perception, rather than simple brightness discrimination. The role of stimulus size apparently depends on whether the task involves a target's visibility or its identifiability.

It is much more difficult to detect a low-intensity image amid a cluster of relatively bright noise pips than to identify the same image when it is seen against a uniform background. Payne-Scott (1948) discussed the importance of this point and suggested increasing the number of samples of noise per unit of time, thereby distributing the noise more evenly over the surface of the tube face. (The advent of computer-aided radar systems, where computers filter out the random pips or noise and transmit only the specific symbol, solves the problems noise once presented.)

Alphabet size is another factor to be considered in establishing a code system.

Alluisi et al. (1957) reported that information is transmitted faster in speeded perceptual motor tasks when the alphabet is larger. They found justification for keeping code alphabets down to a few symbols; their results suggested the optimum number was six.

Green et al. (1956) studied how much time is lost searching for numbers on typical visual displays. They found, first, that large numbers are found more quickly than small numbers. However, if there are so many numbers that the display becomes crowded, smaller numbers are preferable. Second, they found that search time is shorter if all numbers are upright, rather than randomly oriented.

In summary, a successful code will be one that allows observers to recognize each symbol with minimum confusion, even under adverse display conditions. Certain shapes are more distinctive than others and often conform to the requirements of simplicity, symmetry, continuous contour, relatively large enclosed area, either sharp angularity or simple curve, and familiarity in the sense of having a familiar name or meaning.

#### Code Compatibility

Information may be considered to be quantitative, qualitative, or both. Qualitative information concerns kinds of objects or relationships such as friend or foe, bomber or fighter, etc. Quantitative information concerns the extent or magnitude of an object or relationship such as the speed of a missile, the altitude of a bomber, etc. Methods of coding information can also be considered as quantitative, qualitative, or both. Codes that rely on geometric shapes or colors are qualitative codes, because the various colors and various shapes are qualitatively different. Codes based on size, brightness, length, etc., are quantitative codes, because these differences are solely quantitative. Codes are more easily interpreted when qualitative codes are used to code qualitative information and when quantitative codes are used for quantitative information. This is what is meant by code compatibility.

## Code-Reading Accuracy

A criterion of 95 percent accuracy in responding to a code has been agreed upon by a number of experts in the field.\* Accuracy as used here, means the accuracy measured in laboratory experiments; however, this criterion does not necessarily imply that one response in 20 will be wrong in a service situation. It means merely that a code is considered adequate if, under experimental conditions, it elicits the correct response from the observer 95 percent of the time. In the laboratory, the response is usually limited in some way. The observer may be given only one look at a code, or only a short look. Under service conditions, the display will always be there. The observer may take several looks and correct his original impression if it does not agree with a subsequent one. Therefore, there would probably be fewer than one error in 20 responses under service conditions.

Many of the experiments reviewed here have presented stimuli tachistoscopically. But tachistoscopic presentation is not completely analogous to radar-scope presentation. This technique, with its shorter and more rapid presentation of stimuli, places more stringent demands on the perceptual mechanism, than those ordinarily encountered in the applied radar situation.

\* Office of Naval Research Report 166-1-105, November 1949.

## CODES

Conventional scaling methods used on radar scopes usually present two dimensions of information. These two dimensions are usually range and azimuth or altitude and azimuth. If three dimensions -- range, azimuth, and altitude -- must be displayed and quickly and easily interpreted, display problems arise. Conventional display methods code information by angular orientation of the signal (azimuth) and interpolated distance between lines (range and altitude). However, more target information is usually required. Information that might be given includes friend-or-foe identification, type of target (missile, bomber, fighter, interceptor, etc.), target speed and course, or target altitude.

Information may be coded by alpha-numeric characters, geometrics, color, flicker, brightness, line length, angular orientation, inclination of an ellipse, blip diameter, visual number, stereo-depth, or a combination of these dimensions. The relative merits of these coding methods depend on several factors:

- a. The number of absolute identifiable steps (such as the number of colors or sizes that can be identified without confusion) used in a code method.
- b. The immediate interpretability of the code. This refers to the ease with which the operator can differentiate between friend and foe, or between bomber and cargo craft, etc.
- c. The code's effect upon operator fatigue and distractability, or its interference with other codes.
- d. The space required to use the various codes (Baker and Grether, 1954).

### Alpha-Numeric Characters

One way of transmitting information is by giving alphabetical and/or numerical information. Because of man's lifelong familiarity with this type of material, such a system seems best for him.

The number of shapes that an observer can identify correctly is extremely large. Letters and numerals and their combinations are virtually unlimited except for space restrictions and the operator's ability to associate the symbols with the appropriate functions.

With good definition and high brightness contrast, numerals and letters are easily identified when they subtend visual angles as small as five minutes (1/40-inch-high symbols read at a 15-inch viewing distance [Baker & Grether, 1954]).

### Numerals

Green et al. (1953) measured how long it takes to locate a signal coded by a numeral, as a function of the number of other similarly coded signals on the same display. Figure 1 shows how the search time for locating a specific numeral depends on the number, or density, of the numerals on the display. Two numeral orientations were used. In one case the numerals were upright with respect to the observer; in the other case the numerals were oriented randomly.

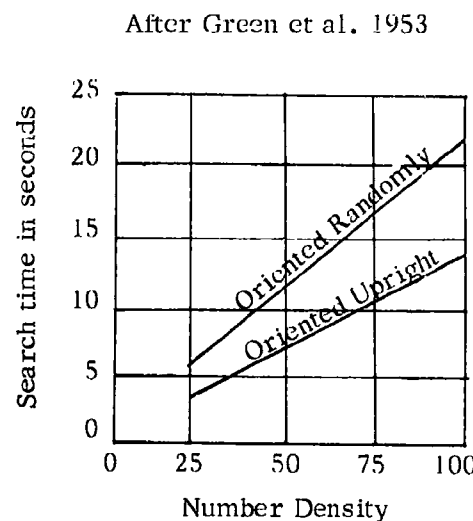


Fig. 1. SEARCH TIME TO LOCATE NUMBER ON DISPLAY

The results of this study indicate:

- a. Search time is shorter when numeral density is less.
- b. Search time is shorter when numerals are upright with respect to the observer than when they are oriented randomly.
- c. When the numerals are clearly defined, adding moderate background clutter has little effect on search time.
- d. When the subject knows what color numeral to search for, other colored numerals do not affect search time significantly.

Dunlap, in 1932, analyzed 122 different license plates attempting to make them more legible and efficient. The results showed that:

- a. A light background with dark numerals gave best results.
- b. Numerals spaced further apart gave higher legibility.
- c. Numerals with a slender stroke were more efficient.
- d. The factors contributing to good legibility, in order of merit, were:
  - (1) Height-width ratio of letters
  - (2) Legend-background ratio
  - (3) Stroke-width of numerals
  - (4) Spacing of numerals
  - (5) Stroke-width ratio of letters
  - (6) Wave-length difference of legend and background
  - (7) Number of single items on plate

Berger, in 1943, analyzed ways to make numerals more legible. (Both Dunlap and Berger were interested in legibility of numerals for road signs and license plates. While many of the results of their experiments are pertinent only under road conditions, those results applicable to radar symbology will be discussed.) In early experiments, Berger showed that the minimal visual angle increases with distance if black-and-white symbols are used with reflected light. This minimal angle is independent of the distance to the eye when very small luminous squares or points are used on a dark background and when the eye is adapted to a medium-light density.



From this it can be concluded that, all other factors constant, distances between details of a numeral are more important for luminous symbols under ordinary night conditions than for black-and-white symbols under daylight conditions with reflected light. Brightness discrimination is the main factor in determining optimal distance between details of numerals, black on white or vice versa, with reflected light. With luminous numerals, the best results should be obtained with an extremely slender stroke and low intensity, leaving maximum space between details. For reflected light, a greater stroke-width will give optimal visibility. The optimal average stroke-width for white numbers on a black background with reflected daylight is in the proportion of 1:5 for the stroke-width and the horizontal distance between the inner borders of the vertical boundaries. For black numbers on a white background, the proportion is 1:2.2 with reflected daylight.

Contrary to Dunlap's results, Berger found that light backgrounds with dark numerals are generally undesirable. As long as the height of the numerals and standard area are kept constant, black numerals on a white background are probably just as recognizable as white on a black background.

Berger also concluded that numerals with complicated structures are more difficult to recognize. He ranked the numbers on recognizability, from most to least -- 2, 0, 7, 3, 5, 6, 4, 8 (9, equal to 6 reversed, and 1, having no inner distance, were not ranked).

In 1951, Brown, Lowery, and Willis used two forms of numerals, Military Standard (MS) 33558 and Berger (Fig. 5), for legibility tests in several stroke-widths. Here they found that a stroke-width-to-height ratio of 1:8 yields optimal legibility. The Berger form was more legible than the MS 33558 form, with the closed 4 significantly more legible than the open 4 under all test conditions.

In 1952, Atkinson, Crumley, and Willis evaluated the legibility of the numeral forms developed in the above 1951 study. The results showed that the proposed Aeronautical Medical Equipment Laboratory (AMEL) numerals (Fig. 5) were superior under all conditions of viewing. The AMEL 1, 3, 4, and 5 are significantly more legible than their MS 33558 counterparts. The AMEL 2, 5, and 9 are significantly more legible than the Berger font. These results led to the specification of the AMEL numerals in Military Specification MIL-M-18012.

Cohen and Webb (1954) attempted to determine which types of coding systems seemed most profitable to explore in designing number systems for visual displays. Twenty-four subjects were tested to determine their speed and accuracy in reading conventional Arabic numbers and five systems of coded numbers (Fig. 2).

<u>CODE NAME</u>	<u>NUMERAL</u>
A. Arabic	1 2 3 4 5 6 7 8 9 0
B. Symbol Arabic	1 2 3 4 5 6 7 8 9 0
C. Dot, Number	. . . . .
D. Dot, Number	. . . . .
E. Line, Number	
F. Dot, Position	· · · · ·

Fig. 2. CODES USED BY COHEN AND WEBB (1954)

An experimental trial consisted of reading, as rapidly and accurately as possible, 100 randomly assorted two-digit coded numbers ranging from 00 - 99, from a deck of 100 3-x-5 cards.

All subjects were fastest and most accurate with the Arabic numbers, and all but three were slowest with the code based on the position of a single dot on a grid. The six-line-matrix Arabic code was read fastest of the symbolic codes, and the three codes based on number of dots or lines were intermediate in terms of reading speed. The authors suggested using an eight-element matrix because it appears to provide an improved series of symbolic numerals as well as a fairly readable series of symbolic representations of the 26 letters of the English alphabet.

Lansdell (1954) compared Mackworth digits with a set of angularly formed elemental matrix numbers (Fig. 3). When compared under poor viewing conditions which gave 51.5 percent correct identifications with conventional numerals, the new digits were identified correctly 67.4 percent of the time. Berger and Tinker gave similar evidence that straight-line and angular figures give better information-handling performance than conventional curved-line figures.

1 2 3 4 5 6 7 8 9 0

Lansdell

1 2 3 4 5 6 7 8 9 0

Mackworth

Fig. 3. LANSDELL DIGITS AND MACKWORTH DIGITS

Alluisi (reported in Muller et al., 1955, Ref. 108) extended Cohen and Webb's work with symbolic Arabic numerals. They studied the compatibility of eight-element, straight-line matrix symbols with habits of reading conventional Arabic numerals. The experiment was designed to select numerals from among two symbols for 4, two symbols for 5, three for 6, and three for 9.

The Cohen and Webb symbols for 0, 1, 2, 3, 7, and 8 were used. The results led to the selection of the numerals in Figure 4.

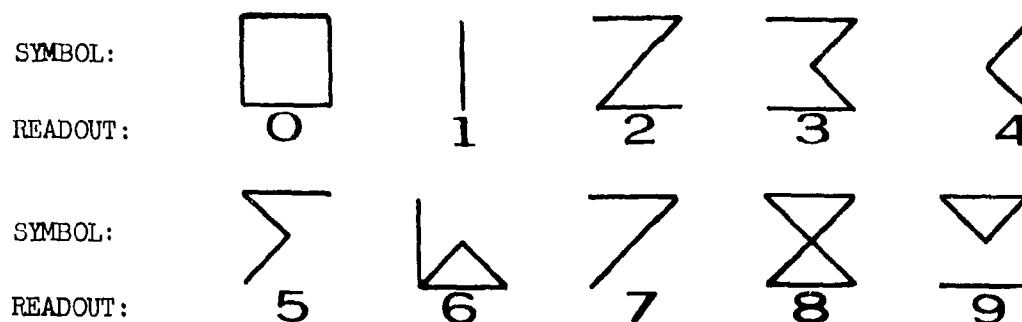


Fig. 4. THE EIGHT-ELEMENT STRAIGHT-LINE MATRIX NUMERALS

Foley (1956) used the Mackworth digits as standard, in comparison with Lansdell digits, to answer several questions: "What are the confusion errors? Is legibility independent of color and background? Are the Lansdell digits more legible than standard sets under varied conditions of exposure and illumination and when viewed obliquely?" (Fig. 3). He found that white on black is more legible at low illumination levels, although the reverse is true at high illumination levels. He found that at different illumination levels, exposure times, and angles of view, the Lansdell digits were significantly ( $p < .01$ ) more legible under all the conditions of the study.

Alluisi and Martin (1957) compared the information-handling performance of subjects in making verbal (number-naming) and motor (key-pressing) responses to two sets of Arabic numbers, one conventional Military Standard 33558 and the other drawn from a matrix of eight straight lines (Fig. 4). They found that conventional numbers were consistently superior in eliciting correct verbal responses. Neither set had a clear-cut superiority with motor responses.

It was concluded that numbers formed by an eight-element printing matrix were not as satisfactory as standard numerals (MS 33558) for eliciting verbal responses. Also, in terms of information-handling (bits per second) time and errors, performance with conventional numerals was consistently superior to performance with symbolic numerals when verbal responses were made. Neither set of numerals led to consistently better motor-response performance. These results agree with those of Cohen and Webb, but conflict with those of Lansdell, Berger, Tinker, and Foley.

A comprehensive study by Harris et al. (1956) analyzed symbols for a matrix-generated symbol-display tube, in this case called a Charactron. The Charactron uses a special CRT tube that can generate almost any type of symbol. There is a small stencil or matrix in the neck of the tube. The tube's electron beam is just large enough in cross section to cover a single character on the stencil. When the electron beam is deflected to a particular character in the matrix, the stencil lets through only those parts of the beam corresponding to the shape of the character.

The first experiment was designed to obtain detailed information concerning numeral legibility. It used Berger, Mackworth, MS 33558, Leroy, and AMEL numerals (Fig. 5) in a simulated display. Characters were about 1/4-inch high and were viewed 60 inches from the CRT. There were five sequences of 100 numerals, five Air Force subjects, five delay times, and five experimental runs. Results showed only six confusions, with more than five percent of the responses to a particular stimulus, but they accounted for more than 50 percent of all the errors. The confusions were 6 with 4 (6 called 4), 3 with 5, 5 with 3, 7 with 2, 2 with 7, and 9 with 7. Also, 8 appeared to have relatively poor legibility, although it was not specifically confused with other characters. It appears that characters are confused for reasons other than that "they look alike." The authors suggest that man has a set of expected forms stored in his memory. Under poor viewing conditions, the perceived form is not the same as that of the stimulus presented, but is degraded. Small details of the character are blurred and diffused. Thus the perceived form may be congruent with more than one expected form, or merely with the wrong one, and the subject will make errors.

When either the 6 or the 4 is presented, the subject is likely to perceive the diagonal plus something in the lower right corner. Since this combination is characteristic of only 4 and 6, neither is often called by any other name. The circle in the 6, because it is small, is frequently perceived as a formless "blob." Thus the perceived 6 is congruent with the expected forms of both 6 and 4 and is often mistakenly called 4. But the 4 is not called 6, principally because the long vertical line is usually perceived. Similar explanations can be made for the other confusions.

BERGER	0	1	2	3	4	5	6	7	8	9
AMEL	0	1	2	3	4	5	6	7	8	9
MS 33558	0	1	2	3	4	5	6	7	8	9
LEROY	0	1	2	3	4	5	6	7	8	9
MACKWORTH	0	1	2	3	4	5	6	7	8	9
LINCOLN LABORATORY	0	1	2	3	4	5	6	7	8	9

Fig. 5. NUMERALS USED BY HARRIS et al. (1956)

This analysis of confusions provided a basis for modifying Mackworth's design. The new numerals are shown as the "Lincoln Design." The 0, 2, 3, 4, 5, and 7 were widened to three-quarters of their height. The short vertical bar of the 5 was lengthened and the point of the 3 de-emphasized. The 4 was changed to be less congruent with the perception of the 6. The upper part of 2 was straightened for more accurate differentiation from 7. No change was made for 8.

Alluisi and Muller (1958) measured information-handling performance with conventional Arabic numerals and six other symbolic codes (Fig. 6). The conventional numerals were used for comparison, and the symbols are ways of encoding information for display on CRT devices.

MS 33558	1 2 3 4 5 6 7 8 9 0
Symbolic	Z 3 4 5 6 7 8 9 0
Arabic Numerals	Z 3 4 5 6 7 8 9 0
Inclination, Simple	↓ ↘ ↙ ↘ ↙ ↘ ↙ ↘ ↙ ↘
Inclination, Clock	⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙ ⊙
Inclination, Binary	↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘ ↘
Ellipse-Axis Ratio	— — — — — — — — —
Color	● ● ● ● ● ● ● ● ● ● DB LB DG LG Gy Y O LR DR V

Fig. 6. CODES USED BY ALLUISI AND MULLER (1958)

The six symbolic codes include a set of straight-line symbols, Arabic numerals, three sets of symbols based on differences in visual inclination of a line, a set of colors and a set of ellipses differing in axis ratios. In a first experiment, subjects pressed one of a number of finger keys for each of the symbols presented. In the second experiment, subjects called out the number assigned to each symbol.

The results showed that verbal responses to the two numerical codes were nearly perfect. But although the verbal responses were more accurate, the motor responses were faster. The numerical codes were superior to the three inclination codes, and all were superior to color and ellipse-axis ratio codes. The study also illustrated that the exact shape of the numeral is unimportant when all figures are of reasonable size and have good contrast.

Soars (1958) began with data about confusions among numerals. Zero was most often confused with 6, and then with 9; 1 with 4; 2 with 8; 5 with 6 and then with 8; 6 with 4; 8 with 6 and 9; and 3, 4, 7, and 9 appear to be confused with other numerals randomly. He devised three new sets of numerals which minimized common elements and emphasized unique elements (Fig. 7). Boldness of stroke and openness of white space within the figure were the two important cues for discriminating between numerals.

A	0	1	2	3	4
	5	6	7	8	9
B	0	1	2	3	4
	5	6	7	8	9
C	0	1	2	3	4
	5	6	7	8	9
D	0	1	2	3	4
	5	6	7	8	9
E	0	1	2	3	4
	5	6	7	8	9

Fig. 7. NUMERAL FORMS USED BY SOARS (1958)

Klemmer and Loftus (1958) designed a study to see if common numerals are better than nonsense forms in situations where perception, discrimination, and memory are involved. A seven-straight-line matrix produced the four sets of 128 different patterns. Ten students were asked to reproduce the patterns exposed to them tachistoscopically for .02 second. The results indicated that tachistoscopically presented forms, whether familiar or nonsense, were discriminated almost equally well. Familiar numerals were reported only slightly better than nonsense figures. It was found that numerals did well when shown alone but were little or no better than nonsense patterns when intermixed. The distortion of form produced by the straight-line matrix might account for the lack of discriminability between the regular and nonsense forms.



It was also found that continuous patterns were discerned more easily than broken patterns. Patterns containing a closed loop of line segments were better than patterns without such a loop. Symmetrical patterns were better than asymmetrical ones. Patterns of only one line segment were better than patterns with more line segments. Practice was a most important variable, with a large and continuing improvement noted throughout the 24 days of testing.

### Letters

Studies of the relative visibility of different letters of the alphabet were undertaken as early as 1881 by Javal, a French oculist. Roethlein (1912) carried out an extensive study of the visibility of isolated characters, using 16 different type faces. The results of all her work gave the following average rank order to the various upper- and lower-case letters of the alphabet, from most to least legible:

WMLJI ATCVQ PDOYU FHXGN ZKERBS

mwdjl pfqyi hghkv rtnu oxaezs

Tinker (1928) reported the correlations between results from 13 different studies of the legibility of upper- and lower-case letters (Tables 1 and 2). There is great variation in the size of the correlations for upper-case letters throughout Table 1. The range extends from -0.58 to +0.89. Table 2 shows consistently that there is fair to good agreement in the orders of legibility found in experiments with lower-case letters. The range of coefficients here is from +0.48 to +0.88. The letter L was frequently at or near the top in legibility, and the letter G was frequently at the bottom.

In his own study of letter legibility, using short exposures and taking percent of correct readings as his criterion of legibility, Tinker found that lower-case letters are confused more readily than upper-case letters. For this reason, the letters t and l should be used as little as possible in displays. Factors which influence the legibility of isolated characters are size, simplicity or complexity of outline, stroke-width and boldness of type face, shading and hair lines, area or white space included within outline, and emphasis or lack of emphasis on differentiating parts. The relative legibility of letters found by Tinker is shown in Tables 1 and 2.

In 1949, Brown and Lowery reported how varying the stroke-width affected legibility of capital letters with fixed height and width. Their main recommendation at that time was a stroke-width-to-height ratio of 1:6 for letters on the plastic plates on aircraft control panels.

TABLE I

Summary of the Orders of Legibility Found in the Investigation  
of the Relative Legibility for the Upper-Case Letters of the Alphabet  
and Their Correspondence as Shown by Rank-Order Correlation<sup>a</sup>

(From Tinker, 1928)

1. Cattell (1886) ... W Z N I D H K N X A Y O G L Q I S C T R P B V F U J E  
Correlation with 2(-.02), 3(.00), 4(.12), 5(.42), 6(-.04), 7(.05), 8(-.16), 9(-.15), 10(-.58),  
11(-.22), 12(-.35), 13(.52).
2. Finzi (1900) ... P U A Q X T D S E W M V Y Z H C N F L R G B K O I  
Correlation with 1(-.02), 3(.16), 4(.09), 5(.21), 6(.33), 7(.28), 8(.28), 9(.11), 10(.14)  
11(.18), 12(-.18), 13(.28).
3. Kirschmann (1908) ... A W I L V X F Y E Z J T K D U S P B M R N O G Q C  
Correlation with 1(.00), 2(.16), 4(.34), 5(.36), 6(-.46), 7(.47), 8(.51), 9(.46), 10(.31), 11(.37),  
12(.33), 13(-.07).
4. Roethlein (1912) ... W M L J I A T C V Q P D O Y U F H X G N Z K E R B S  
Correlation with 1(.12), 2(.09), 3(.34), 5(.51), 6(-.46), 7(.70), 8(.87), 9(.38), 10(.06), 11(.14),  
12(-.09), 13(.13).
5. Kirsch (1920) ... O L W Y V A T N D X C M Z P E H U K S F Q R G I B  
Correlation with 1(.42), 2(.21), 3(.36), 4(.51), 6(.30), 7(.58), 8(.72), 9(.19), 10(.10),  
11(.33), 12(-.03), 13(.46).

<sup>a</sup> Order is (left to right) from most to least legible. Letters connected by an underscore were of equal legibility.

TABLE 1 - Continued

6.	Hartridge and Owen (1922) ... L A J E N H X P F Z U T D Y V K C B O R S Correlation with 1(-.04), 2(-.33), 3(.46), 4(-.46), 5(.30), 7(.72), 8(.15), 9(.78), 10(.71), 11(.79), 12(.50), 13(-.08).
7.	Ewing, Gothic (1922) ... L A T V H Z E N P F C K O D X R S B Correlation with 1(.05), 2(.28), 3(.47), 4(.70), 5(.58), 6(.72), 8(.54), 9(.62), 10(.53), 11(.60), 12(.24), 13(-.18).
8.	Ewing, Block (1922) ... L T V U C O Y F P D Z N E R S G H B Correlation with 1(-.16), 2(.28), 3(.51), 4(.89), 5(.72), 6(.15), 7(.54), 9(.50), 10(.22), 11(.38), 12(.08), 13(.24).
9.	Ban. Hart. & Lyth., I (1926) ... L J I A P T Z F U E D X C N H K O W Y R B M Q S G V Correlation with 1(-.15), 2(.11), 3(.46), 4(.38), 5(.19), 6(.78), 7(.62), 8(.50), 10(.83), 11(.89), 12(.70), 13(-.06).
10.	Ban. Hart. & Lyth., II, (1926) ... J L P Z E F D A T U N H K B C I R W Y S X O M V G Q Correlation with 1(-.58), 2(.14), 3(.31), 4(.06), 5(.10), 6(.71), 7(.53), 8(.22), 9(.83), 11(.88), 12(.86), 13(-.04).
11.	Banister, I (1927) ... J A L Z P N U E F I D T C Y X H O R S B K W V M G Q Correlation with 1(-.22), 2(.18), 3(.37), 4(.14), 5(.33), 6(.79), 7(.60), 8(.38), 9(.89), 10(.88), 12(.76), 13(-.05).
12.	Banister, II (1927) ... L F J B E Z N A T I D K U H P C R V S O X Y W M G Q Correlation with 1(-.35), 2(-.18), 3(.33), 4(-.09), 5(-.03), 6(.50), 7(.24), 8(.08), 9(.70), 10(.86), 11(.76), 13(-.35).
13.	Tinker (1927) ... W Z X O D M P Y U N J Q K H C S V L T F B R G E A I Correlation with 1(.52), 2(.28), 3(-.07), 4(.13), 5(.46), 6(-.08), 7(-.18), 8(.24), 9(-.06), 10(-.04), 11(-.05), 12(-.35).

TABLE 2

Summary of the Orders of Legibility Found in the Investigation  
of the Relative Legibility for the Lower-Case Letters of the Alphabet  
and Their Correspondence as Shown by Rank-Order Correlation<sup>a</sup>

1. Cattell, Short Exposure (1886) .. d k m q h b p w u l j t v z r o f n a x y e i g c s  
Correlation with 2(.62), 3(.57), 4(.58), 5(.56), 6(.64), 7(.74).
2. Sanford, I, Distance (1888) .. m w d q v y j p k f b l i g h r x t o u a n e s c z  
Correlation with 1(.62), 3(.88), 4(.68), 5(.88), 6(.58), 7(.68).
3. Sanford, II, Short Exposure (1888) .. w m q p v y j f h r d g k b x l n u a t i z o c s e  
Correlation with 1(.57), 2(.88), 4(.64), 5(.77), 6(.53), 7(.68).
4. Dockeray, Peripheral Vision (1910) .. m d k w p b o q y j r x a g l v z i s t u h n c f e  
Correlation with 1(.58), 2(.68), 3(.64), 5(.49), 6(.61), 7(.66).
5. Roethlein, Distance (1912) ... m w d j l p f q v i h g b k v r t n c u o x a c z s  
Correlation with 1(.56), 2(.88), 3(.77), 4(.49), 6(.48), 7(.56).
6. Kirsch, Distance (1920) ... d p q h w m o b v u y k c e x g l r z a i n s t f  
Correlation with 1(.64), 2(.58), 3(.53), 4(.61), 5(.48), 7(.60).
7. Tinker, Short Exposure (1927) .. k d q b p m w f h j y r t x v z c o a u g e i n s l  
Correlation with 1(.74), 2(.68), 3(.68), 4(.66), 5(.56), 6(.60).

<sup>a</sup> Order is (left to right) from most to least legible. Letters connected by an underscore were of equal legibility.

In 1951, Long and Reid undertook a laboratory program of several studies to explore some of the factors determining the legibility of letter and word patterns formed by elements or dots. The general plan was to investigate the effect of the various types and degrees of stimulus change on recognition or legibility of letter patterns by manipulating the following variables: (a) number and size of cells or elements in the matrix; (b) types of degradation; (c) degrees of degradation; and (d) brightness level at which the stimuli were viewed (Fig. 8).

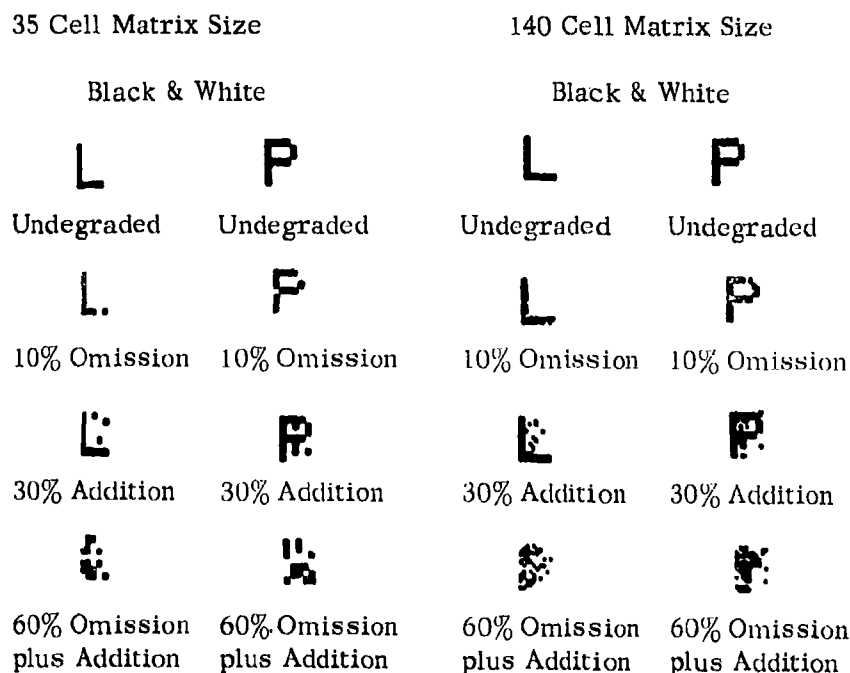


Fig. 8. STIMULI USED BY LONG AND REID (1951)

Four subjects viewed 520 slides under two brightness conditions, making a total of 1040 observations for each subject. The results indicate that recognizing letters correctly depends on the sharpness of the image on the screen. Increasing the number of elements in equal-area matrices makes it easier to recognize degraded letters. Increasing viewing brightness from 6.5 to 87.5 millilamberts does not significantly alter numbers of correct recognitions. This study utilized letters printed only in black on white.

The purpose of the second study was determining the degree to which letters printed in "gray scale," i.e., printing signal and noise elements in brightness proportional to their respective intensities, were susceptible to the various types and degrees of degradation previously studied. The results were similar to those found in the first study.

A third study added four-letter words and four-letter "jumbles" printed in both gray scale and black and white. Other stimulus variables were the same as in the two earlier studies. Again, the same factors as in the previous studies were found to decrease legibility. Legibility loss was minimized by using a larger matrix and by printing in the gray scale. Four-letter words and single letters were equally legible; four-letter jumbles were less legible under all experimental conditions.

The authors suggest that if it is not technically feasible to control signal degradation in equipment design, special effort should be made to avoid the simultaneous combination of addition and omission of elements. The two alternatives are either a highly sensitive system allowing all of the signal and some noise to appear, or a highly-insensitive system, precluding noise, but omitting some of the signal elements. If signal and noise are printed in different brightnesses according to their intensities ("gray scale"), recognition is improved. Simultaneous use of "gray scale" and increased matrix size affords the greatest improvement in recognition, especially when both types of degradation are present simultaneously. Also, when coded material is used, it is suggested that the code consist of discrete letters or meaningful letter groups rather than meaningless groups or jumbles of letters.

Brown (1953) and Baker and Grether (1954) conducted studies which resulted in the development of a standard alphabet for use on military equipment (Fig. 9). Brown's study demonstrated that the military upper-case letters are more legible than the commercial type.

ABCDEFGHIJKLMNOPQRSTUVWXYZ

Fig. 9. MILITARY STANDARD 33558 OR LEROY LETTERING

Hodge (1962) compared the legibility of black upper- and lower-case letters read individually against a white background under a high level of white illumination. The letters were drawn with the Keuffel and Esser Leroy lettering set (Fig. 9). Seven height-to-stroke-width (H:SW) ratios were used in order to determine the optimum ratio for both upper-case and lower-case letters. Subjects were 15 students, who identified randomly ordered letters on 56 cards shown in a special viewing apparatus.

The results confirmed those of Berger (1956), Crook et al. (1954), and Tinker (1932). Some obscure peculiarity of lower-case letters (height notwithstanding) renders them less legible than upper-case letters. These results do not indicate that lower-case letters should not be used in visual displays, but rather that they are less legible than upper-case letters.

The optimum height-to-stroke-width ratio was 5.6:1 for upper-case and 4.6:1 for lower-case letters. These H:SW ratios were also recommended by Baker and Grether (1954).

Hodge found the order of legibility for his letters from most to least legible to be (underlined letters are of equal discriminability):

L A J Z T U E P S M V N F W R D C X I K Y B O G H Q

m p d b c u y v w h n z q k g r x j o s f e i t a l

### Geometrics

Gestalt theorists emphasize that the concept of "simplicity" or "good figure" can be applied to geometric figures. According to this concept, the circle is the simplest figure and, for this reason, should be identified more easily than other forms. Helson and Fehrer (1932) demonstrated that this is not so. They found that the circle ranked after the rectangle and triangle in perceptibility. Similar results have been found by Collier (1931), Kleitman and Blier (1928), Munn and Geil (1931), and Whitmer (1933). Although the order of discriminability for different forms varied in these studies, they all agree that the circle is neither exceptionally good nor poor in discriminability.

A study by Hochberg et al. (1948) offers evidence supporting the Gestalt concept of "simplicity." Using three figures -- a circle, rectangle, and block cross of equal area -- they found the circle most perceptible, followed by the square and the cross. But an experimental design using so few forms can hardly be considered an adequate test of so broad a hypothesis.

Casperson (1950) investigated the discrimination thresholds of six geometric forms to relate their relative discriminability to three quantifiable aspects of their construction: (a) maximum dimension, (b) area, and (c) perimeter. He wanted to see how these aspects could be used to predict the discriminability of geometric forms. The six basic forms were the ellipse, rectangle, triangle, diamond, cross, and star (Fig. 10). Twenty male subjects judged 24 sets of 30 figures as rapidly and accurately as possible. The stimuli (solid-black photo prints mounted on heavy white paper, 6 1/2 inches square, containing nine figures in random order arranged in three rows and columns) were exposed from the far end of a 36-inch square box, at a distance of about 20 feet from the subject. Percentages of correct responses were calculated.

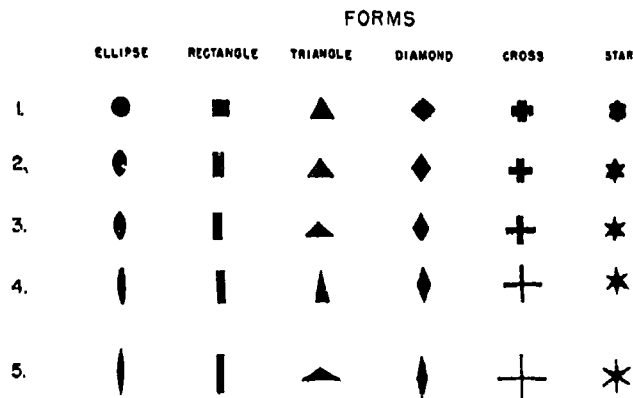


Fig. 10. FORMS USED BY CASPERSON (1950)

Area was found to be the best measure of discriminability for ellipses and triangles. Maximum dimension predicted discriminability best for rectangles and diamonds. Perimeter was the best predictor for stars and crosses. The results confirmed early reports that circular and elliptical shapes are difficult to identify. These results indicate that the Gestalt principle of "simplicity" is inadequate as a predictor of the relative discriminability of ellipses, rectangles, triangles, diamonds, crosses, and stars. In ranking the discriminability of these six figures, it was found that the triangle, cross, and rectangle consistently maintained their ranks within the first three positions, while the star, diamond, and ellipse occupied the lower three positions, regardless of measure. When the ellipse became a circle,



it ranked in third place. Casperson concluded that increasing the maximum dimension, perimeter, or complexity of a form, in most cases, increased the probability of its being seen.

Sleight (1952) tried to obtain some information on the relative discriminability of different geometric forms when the subject had to deal with a complex panorama of them. The stimuli were six each of 21 different geometric forms (Fig. 11), constructed of black paper and mounted on 1-1/4-inch clear lucite squares. The figure was the maximum size which could be inscribed within a one-inch circle. A 25-inch circle painted flat white was used as a display background. The essential task was to sort all six of a given form into a compartment as accurately and quickly as possible. Subjects always sorted from 126 items.

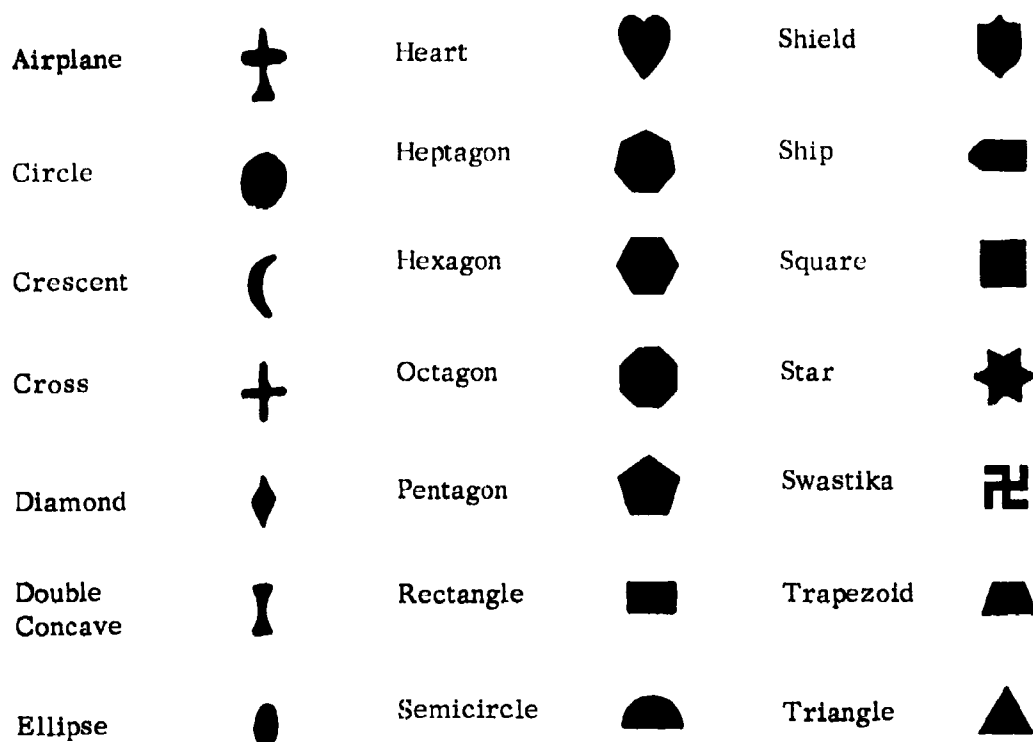


Fig. 11. FORMS USED BY SLEIGHT (1952)

The results showed that the forms sorted most quickly were, in this order: swastika, circle, crescent, airplane, cross, and star (Table 3). The hexagon took approximately ten times longer to sort than did the swastika.

TABLE 3

Relative Discriminability of Geometric Forms as Determined by  
(a) Mean Selection Order and (b) Mean Sorting Time<sup>a</sup>

Form	Rank by Selection Order	Rank by Sorting Time
Swastika	1	1
Cross	2	5
Star	3	6
Airplane	4	4
Crescent	5	3
Diamond	6	9
Circle	7	2
Heart	8	12
Triangle	9	10
Double-concave	10	19
Semicircle	11	14
Shield	12	17
Rectangle	13	8
Ellipse	14	7
Ship	15	13
Square	16	11
Trapezoid	17	16
Pentagon	18	15
Hexagon	19	21
Octagon	20	18
Heptagon	21	20

<sup>a</sup> Rank-order correlation = .79

When the data are ranked by the subjects' selection order (Table 3), the swastika is first; the cross second; and the star third. The airplane, crescent, diamond, circle, heart, and triangle follow in that order.

There was a high positive correlation between the ranking of figures by sorting time and the ranking based on subjects' order of selection of items by "attention-getting" value.

Gerathewohl and Rubinstein (1953) dealt with the following problems:

- a. Relative discriminability of a circle, square, triangle, rectangle, ellipse, and trapezoid.
- b. Effect of size of signal upon its recognizability.
- c. Differences among individuals in their ability to recognize signals.
- d. Position of the target as a factor influencing discrimination.

Twenty-four untrained observers were used in the study.

Two targets of each form were used so all pairs could be placed in different attitudes in relation to the center of the target circle. The targets were presented with simulated ranges of 10, 20, and 50 miles. The simulated altitude was 26,000 feet. The results showed that the triangle, circle, and trapezoid ranked relatively high, while the square, rectangle, and ellipse ranked low; both position and geometric shape seemed to contribute to these differences. A target was more easily recognized as its size increased. Individuals differed significantly in ability to identify targets.
























It should be pointed out that this study was not completed because of equipment breakdown, that the number of subjects was relatively small, and that only one identification of each of the 12 forms was recorded at each range.

Gerathewohl (1953) repeated the study to compare the relative discriminability of squares, rectangles, crosses, and circles under conditions of heavy noise. The other conditions were repeated as above.

Under noisy conditions the triangle ranked highest, followed by the square, then the circle, and finally the cross. Many more errors were made in this experiment than in the previous one, probably because of the noise. A marked tendency for all figures to be called triangles probably accounts for the triangle's high rating. But all the results must be interpreted in the light of the unstandardized conditions under which the study was carried out.

Using noise as a variable, Leonard and Fitts (reported in Alluisi, 1960) found that man acts to filter random disturbances to some extent: repeated looks at figures distorted by visual noise were found to benefit performances.

A series of 21 symbols was designed by Harris et al. (1956) for display on a special CRT with matrix (Fig. 12). Simple names were chosen for the symbols, and ten airmen were thoroughly trained in naming the symbols. The symbols were painted on a simulated Characteron (see page 19). The subject's task was to verbally identify each symbol, by name, when it was presented.

The open and solid triangular forms were sometimes confused with each other, but differently oriented triangular forms were almost never confused. The rounded characters,     tended to be confused with each other. The larger pointed figures    were called rounded ones     more often than the reverse. The double cross  was sometimes perceived as a large, round blob much like the perceived form of the several round characters, although the rounded figures were never perceived as pointed. Diamond  was confused with ring  and O-bar ; propeller  was confused with open down triangle  and solid down triangle . The more elongated symbols had excellent legibility. The ring, plus, and star    were readily degraded to a dot-like form. Anchor  and flag  were virtually error free.



























						
ROCKET	GUN	PROPELLER	ANCHOR	FLAG	OPEN UP	OPEN DOWN
						
PLUS	STAR	DOUBLE CROSS	BLOCK	OPEN SQUARE	SOLID UP	SOLID DOWN
						
RING	CHECKER	BULLS-EYE	O-BAR	LARGE DOT	SMALL DOT	DIAMOND



Fig. 12. FORMS USED FOR CHARACTERON TUBE

The overall results suggest the sources of confusion to be avoided in designing symbols. For example, variations of a single geometric form, such as sets of round, pointed, and triangular characters should be avoided. It is important to consider the forms the operator expects to see, as well as the effects of stimulus degradation.

Based on the known facts of legibility and on the two previous studies by Harris et al. the authors designed a complete set of characters for a CRT matrix. They used Mackworth letter designs and Lincoln Laboratory numerals. Of the eight special symbols,

gun	
rocket	
0-bar	
flag	
ball	

were taken from the set used in the experiment on symbols. The

radar	
post	

were simplified versions of corresponding symbols on the previous matrix. A

plane	
-------	--

was also used. In all, there were 44 symbols. The observer was required to read the characters aloud as fast and as accurately as possible. Only 521 of about 34,000 readings in the studies were errors. Even this small number of errors can be accounted for in terms of the large number of forms to be remembered and the difficulty of associating the proper name with each form. Also the emphasis on speed was likely to account for some errors.

Blair (1957) studied three sets of symbols (Fig. 13) proposed for use on radar scopes. One problem was to determine visual recognition thresholds for these symbols by having subjects give "number assigned to symbol" and "meaning assigned to symbol." The other problem was to obtain time and error scores for identifying and discriminating command and enemy symbols from tracked and friendly symbols. Results indicated that performance depended on the set of symbols used, that performance was poorer when the number of symbols increased, and that subjects responded slower when density per scope area increased. The rank order of sets of symbols in terms of performance was Row I, Row II, Row III.


















	Command	Enemy	Tracked	Friendly
I				
II				
III				

Fig. 13. SYMBOLS USED IN BLAIR STUDY

Dardano and Donley (1958) investigated the discriminability of the symbols Blair used in his study. These symbols were selected for convenient generation from sine-waves and for ease of encoding them with additional information.

The five figures could be grouped into three levels of discriminability;

 and ,  and , and .

Straight lines were a characteristic of the most discriminable symbol. The circle was less discriminable than a compound figure. The cross-within-circle was confused (three times out of four) with the complete circle. The outer contour of the circle became dominant over its interior lines.

The results of this study indicated that the cross-within-circle and cross were most discriminable, the circle and half circle less discriminable, and the three-quarter circle least discriminable.

The study of these symbols, excluding the three-quarter circle, was repeated under field conditions by Dardano and Stephens (1958) to determine (a) any change in the discrimination order reported in the earlier study, (b) optimal size for presentation of symbols, (c) effect of size on discrimination, and (d) effect of unique characteristics of electronic generation of symbols on their relative discriminability.

Relative discriminability of the four symbols did not conform to the ranks resulting from the earlier study. The cross remained in the more discriminable group and the half circle in the less discriminable group. The circle shifted to the more discriminable and the cross-within-circle to the less discriminable level.

The differences between these pairs were independent of size level. Minimum size at which discrimination of symbol was not impaired was between 3/16 inch and 5/16 inch; at 1/8 inch there were extreme increases in scanning time and omissions for all symbols. The size at which these shapes cease to function effectively as radar symbols would seem to lie between 1/8 inch and 3/16 inch.

Subjects did not agree in their ratings of the ease with which the shapes could be discriminated. Determinants of symbol discriminability were assumed to be luminosity gradients around the contours of the figures at lower size levels, and similarity of a shape to the remainder of shapes at higher size levels.

Bowen et al. (1959) attempted to establish the absolute discriminability of a set of 20 geometric shapes. In particular, their study took account of the conditions which may exist on operating radar displays, and examined the absolute discriminability of geometric shapes under both visually clear and visually degraded conditions. Because of the general practice of using simple shapes, such as circles or triangles, to represent major categories of information, this project used only such primary symbols.

The shapes were selected so that each should appear distinctively different, each should appear simple, have few elements, and in some sense be symmetrical.

Twenty shapes were used not only to reduce the chance of missing a potentially good shape, but also to allow ample opportunity for confusion between shapes (Fig. 14).

The primary purpose of the first experiment was to determine the rank discriminability of these 20 symbols under various conditions of noise, blur, and distortion. A secondary purpose was to select sets of symbols which, when used as a group, would yield minimum confusion between symbols. The 240 test conditions were administered to seven subjects.

It was found that (a) visually normal observers are not significantly different from one another in overall accuracy of response; (b) increasing the amount of noise deteriorates performance; (c) distorted symbols are not recognized as well as undistorted ones; and (d) blur does not affect symbol recognition significantly when other display conditions are fairly good -- but when other conditions are poor, blur will combine with the other factors to degrade recognition.

Table 4 gives the optimum subsets of symbols with three articulation scores under best, average, and worst conditions.

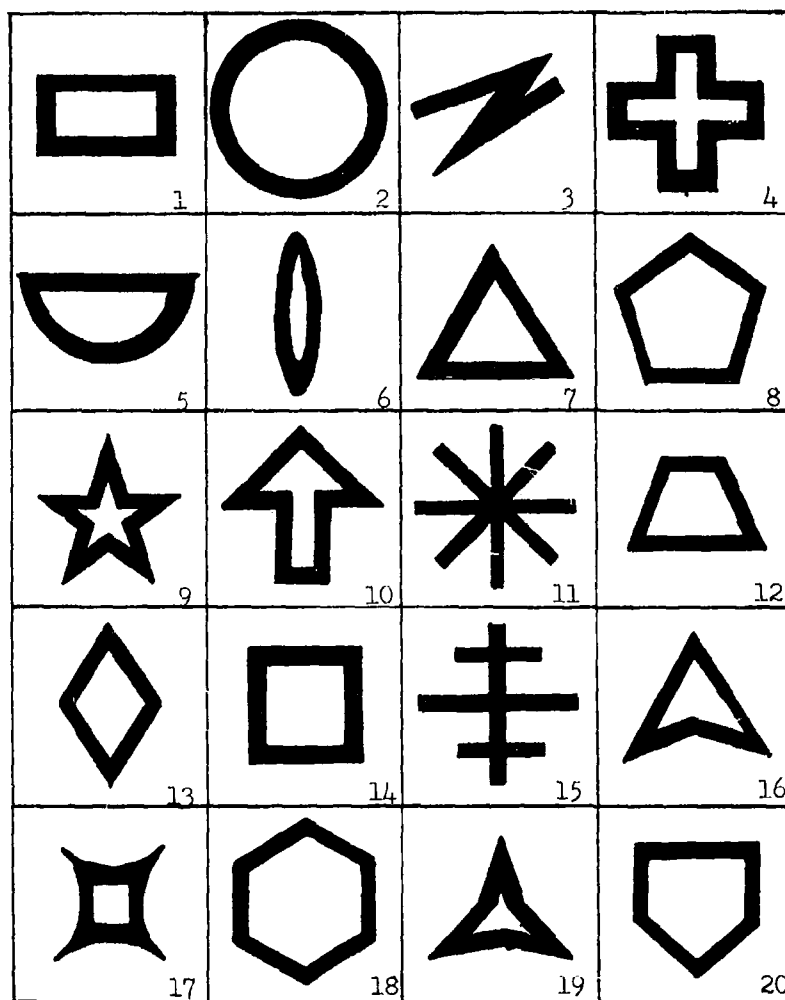


Fig. 14. SYMBOLS USED BY BOWEN et al. (1959)



TABLE 4

Optimum Sets of Symbols Recommended by Bowen et al.

Number of Symbols in Set	Recommended Symbols <sup>a</sup>	Articulation Scores for Conditions <sup>b</sup>		
		Best	Average	Worst
2	1 & 2; 1 & 3; 2 & 3; 7 & 14; 5 & 7; 5 & 14.	1.0	1.0	1.0
3	1, 2, & 3; 5, 7, & 14.	1.0	1.0	1.0
4	1, 2, 3, & 4; 5, 6, 7, & 14.	1.0	.99	.99
5	1, 2, 3, 4, & 5; 4, 5, 6, 7, & 14.	1.0	.98	.91

<sup>a</sup> See Figure 14 for the symbols referred to in the chart.<sup>b</sup> Articulation scores are the probability of a correct response for the recommended sets of symbols.

While the sets given in Table 4 represent optimum combinations, any combination drawn from the first ten symbols should yield good results. In sets where a square is given, a rectangle may be substituted with only a small loss, but a square and a rectangle should never be used together. In general, symbols 15, 16, 17, 18, 19, and 20 should not be used. The results indicate that the number of symbols should be kept small and, under adverse display conditions, should not exceed six.

The rank order of symbols obtained from the average of all conditions and for all observers is changed little for any specific observer or condition of display degradation.

The second experiment was designed to provide information about optimum size and stroke-width of symbols to be used in tasks similar to those in operation centers.

The stimuli were a circle, a variation of a cross, a square, and a triangle, in three sizes (.25, .375, and .50 inch) and three stroke-width-to-height ratios (1:6, 1:8, and 1:10). Each symbol appeared 20 times.

The subject was to count the times a specific symbol appeared on a display as accurately and quickly as possible.

The cross was counted most quickly, probably because it was the only line figure in the group. The triangle was found to be poorest. The half-inch symbols were counted fastest, with stroke-width-to-height ratio making no difference for this size. When the symbols were smaller, however, the thinner stroke-widths were superior.

It was recommended that stroke-width-to-height ratios of 1:8 to 1:10 and symbols 0.4 inch or larger are best for viewing, up to seven feet. The rate at which the symbols were counted under best conditions was one symbol every .7 second. For many situations one symbol per second is likely to be the fastest performance rate. This differs from the results of the AVID study quoted earlier.

The above data are necessary for the design of a good symbol code, but may not be sufficient; other features have to be taken into account. Table 6 in the Recommendations section provides estimates of the minimum satisfactory sizes of dots and small rectangles that may be used, if additional information is necessary.

Fried (1959) used these symbols --  $\bigcirc \oplus + \smile$  -- and subjected them to three degrees of simulated jamming. The jamming patterns raised the detection time for the symbols. For the extreme jamming condition, detection time was nearly doubled. For the  $\bigcirc \oplus \smile$ , detection time was approximately the same under no noise and mild noise. The  $+$  symbol was detected significantly faster than the other symbols. In no case was there confusion or omission of symbols more than 10 percent of the time for any of the conditions.

Coules et al. (1960) devised a study to determine whether different kinds of polygons were equivalent in judged complexity. They also studied the judged complexity of irregular forms under different degrees of visual noise and attempted to determine the effect of exposure duration on judged complexity. The stimuli were 20 irregular shapes generated by a random method. They were rated by 20 subjects who viewed the shapes under three signal-to-noise ratios and two exposure durations. The results indicate that forms differ significantly within the polygon categories. There are distinctive differences in judged complexity among different forms having the same number of sides. Visual noise affects judged complexity of forms and tends to make simpler forms more complex. Exposure duration did not have an important effect on judged complexity of forms.

This study seems to show that polygon forms would be a poor choice for use on visual displays.

## Color Coding

Color commands attention readily and stands out in experience. It stimulates quick reactions and provides clear cues in situations where the observer must sort out of a complex pattern of targets certain targets to which he must give special attention. Thus color would seem to present an excellent coding dimension which could easily be combined with other types of code alphabets.

The apparent color of an object depends on numerous factors, including the distribution of the energy that is transmitted from the object to the eye, the nature of the background against which the object is viewed, and the eye's state of adaptation. A surface's apparent color varies when the illumination's color temperature is changed and when other colored objects are introduced into the field of view. For such reasons color must be used with great care when more than four or five coding categories are required.

Even though colored phosphors have been developed for use on cathode-ray tubes, it is still difficult to produce satisfactory colored symbols electronically. Clearly defined hue differences can be obtained under standard laboratory conditions, but they are not always achieved under ordinary service conditions. Where users must discriminate electronically generated color-code symbols on phosphors, it is conservatively estimated that no more than four absolutely discriminable hues -- red, yellow, green, and blue -- can be generated within the limitations imposed by present technical developments.

Eriksen (1952) investigated speed in locating objects on a visual display when the various classes of objects on the display differed from one another on only one of four dimensions: form, hue, size, and brightness. He found that location time for hue differences was significantly shorter than for form differences, and that location time for hue and form were significantly shorter than for either brightness or size. Thus, hue was superior to form in coding objects on visual displays when subjects were required to locate objects.

Cohen and Senders (1953) did a study to determine whether shape or color coding would reduce time and errors in locating particular dials in visual displays. Their results indicated that, for locating dials, the color-coded dials permitted better performance than the shape-coded dials.

A ten-symbol alphabet developed by Muller et al. (1955) has been found to have a high degree of discriminability (Table 5).

TABLE 5

## Ten-Symbol Color Alphabet

Color Name	Wratten (Kodak) Filter No.
1. Dark Blue	45A
2. Light Blue	38A
3. Dark Green	58 (2 layers)
4. Green	52
5. Gray	N.D. 0.6
6. Yellow	15 G
7. Orange	106
8. Light Red	24
9. Dark Red	29 + CC40B
10. Violet	34A

Muller (1955) reported data on reaction-time and information-handling rates for four experimental and four control groups that made verbal (number-naming) and motor (key-pressing) responses to spatial and color symbols. The major findings were (a) performance with ten lights as symbols was greatly superior to performance with ten color symbols; and (b) with color symbols, verbal and motor responses were equally quick.

Anderson and Fitts (1958) attempted to answer the question, "How much information can subjects report after the tachistoscopic exposure of a group of symbols, as a function of the information content of the symbol and the method of information coding?"

Three levels of stimulus dimensionality were studied. Alphabets of symbols consisted of nine color patches, nine black numerals, and black numbers on colored backgrounds. The colors were red, yellow, blue, green, violet, flesh, orange, pink, and indigo.

With the first two alphabets, four message lengths were used: 3, 4, 5, and 6 symbols. The information varied from 9.51 - 19.02 bits per message. In the color-numeric alphabet the messages were held to three symbols, with information varying from 6.34 - 19.02 bits per message. Symbols were exposed for 0.1 second to 12 subjects sitting 10 or 12 feet from the screen. There was an alerting signal three seconds before each message exposure. Subjects recorded first the color symbol, then the number; they had to respond to all stimuli.

Results show that performance with the color-numeric alphabet was greatly superior to performance with either colors or shapes alone. The average amount of information transmitted with three compound symbols was 16.97 bits. This was significantly greater ( $p < .01$ ) than the amount transmitted for six numerals (14.30 bits), and this in turn was significantly better than performance with six color patches (7.69 bits). Performance with colors was significantly better for messages containing only four symbols than for longer messages. Performance with numbers was slightly better with five than with six symbols. Performance with compound symbols apparently had not reached a peak for the highest information messages used.

In a second experiment almost the same alphabets were used with messages containing 12.68 to 25.36 bits. Twelve new subjects went through the same procedures as in the first experiment.

























The results provided strong confirmation of the earlier findings. The use of color-numeric symbols led to significantly better performance than did colors or numbers alone.

In the study by Alluisi and Muller (1958), it was found that the ten-color code was inferior to numerical codes in information-handling situations.

Similar results were found by Conover and Kraft (1959), who compared color and shape coding. They found that the maximum average information transmission rate for color was 10.44 bits per exposure, while for numerals it was 14.94 bits. A combination of shape and color gave 18.6 bits of information per exposure.

It was also found that the maximum number of hues which can be used for coding ranges from five to eight. Electronically generated color codes using short-persistence phosphors are still more restrictive, since they permit no more than four absolutely discernible hues. The precise number of identifiable hues depends on the viewing conditions and the percentage of population which must read the code without error. It is difficult to control the visual environment for color perception, since color judgments are influenced by many aspects of the surrounding conditions, as well as by variation within a given observer.

Similar results were found by Hitt (1961). He chose five different coding methods: numeral, letter, geometric shape, color, and configuration (Fig. 15). He found that searching and recognition are two independent task factors. Within the limits of his study, color coding and numeral coding were superior to the other coding methods. If greater emphasis is to be placed on correct recognition of symbols rather than reducing search time, numeral coding is superior to color coding.

Numeral	1	2	3	4	5	6	7	8
Letter	A	B	C	D	E	F	G	H
Geometric Shape								
Configuration								
Color <sup>a</sup>								

<sup>a</sup> No attempt was made to hold saturation and brightness constant

Fig. 15. SYMBOLS USED BY HITT (1961)

Newman and Davis (1961) examined whether adding color, among other dimensions, to a symbol reduced the total number of symbols needed on a display. The colors used were red, yellow, and green (see page 63). Subjects had to search for, locate, and decode the compound symbols. The results indicate that symbol-plus-color coding is superior for both localizing and decoding tasks.

Smith (1962) studied how color coding displays affects visual search time. Twelve subjects each viewed a series of 300 displays which varied in display density, number of colors used, and the particular color of the target, with either a white or black background, under conditions where the subjects either knew the color of the target in advance, or did not. Neither the particular color of the target nor the display background had any significant effect on search time. However, search time increased regularly with increasing display density. With multicolor displays, search times were considerably shorter when the color of the target was known in advance than when the target color was unknown. When subjects had no advance knowledge of what color target to look for, search times were the same as for single-color displays.

In 1963, Smith had six subjects view a series of displays of colors printed over each other (five colors) and, in each case, count the occurrences of a particular target digit. He found that legibility decreased regularly as degree of symbol overprinting was increased. There were also incidental differences in legibility among the particular number symbols used. But these differences were small compared to those attributable to color. This suggests that color is potentially more influential than shape in determining the legibility of overprinted symbology.

The results of Smith's earlier studies bear a striking resemblance to those obtained by Smith and Thomas (1964). In the latter study, eight subjects counted a specified color or shape of object on displays with 20, 60, or 100 items. The colors were green, blue, white, red, and yellow. The shapes included military symbols (radar, gun, aircraft, missile, ship), geometric forms (triangle, diamond, semicircle, circle, star), and aircraft shapes (C-54, C-47, F-100, F-102, B-52). Counting time and errors increased as the density of the display increased. Counting based on a five-value color code was faster and more accurate than counting based on any of the three shape codes. Color counting was not affected by the particular shape code on which the colors were superimposed. Shape counting was somewhat faster and/or more accurate when there was only one color in a display, and vice versa. There were differences in counting performance among the three shape codes and among certain of the symbols within the shape codes. The military symbols were counted faster than the geometric forms, and the geometric forms were counted faster than the aircraft shapes. The military symbols ranked in the following order in speed of counting: ship, missile, aircraft, gun, and radar. The most discernible geometric form proved to be the star, followed by the circle, semicircle, diamond, and triangle. The discernibility of the aircraft shapes was generally poor. The study confirmed that there were small differences among the particular code colors used; yellow, red, and white were most legible.

The results of these studies indicate that color is a superior coding dimension when the operator must simply locate targets. When he must also identify targets, however, color is most useful when combined with other symbols, such as numerics or geometrics.

## Flicker Coding

From a psychological viewpoint, flicker is an undesirable coding medium. It is critically influenced by brightness and size. With high flicker rates, targets must have high brightness and moderately large size. Flickering light, especially at certain repetition rates, is annoying to view. A large display composed of many winking, blinking lights might be nothing short of maddening. On the other hand, there may be some occasions when displays should be annoying. Sometimes it will be vital to attract attention to a danger zone. Under such circumstances one can make good use of the very aspects of flicker that make it generally undesirable. The periphery of the retina is extremely sensitive to intermittent stimulation between 2 and 60 cycles per second. These frequencies are recommended only to attract attention. This flicker range may also produce apparent movement, which may or may not be advantageous in the display situation.

In 1948, Gebhard reported that flicker coding offered a possible, but not overly hopeful, method of representing data. He proposed the use of coarse flicker which stayed well below the fusion frequency. The frequencies available for scaling into a usable code system range from about 1/2 to 30 flashes per second. To obtain flicker without fusion, at 30 flashes per second, retinal intensities must be about 10 millilamberts. There are about 15 discriminable steps between 1/2 and 30 flashes per second. These discriminations have poor reliability. Gebhard suggested it would be most profitable to use simple on-off patterns, like blinker codes.

Gerathewohl (1951, 1952, 1953) studied the conspicuousness of flashing light signals. He found that flashing light signals are more conspicuous than steady ones when brightness contrast is low. In 1954, he investigated how conspicuous flashing light signals are at three different flash frequencies and durations -- one, two, and four flashes per second, and durations of 1/2, 1/4, and 1/8 second. The evidence indicates that when subjects do a very complex psychomotor task, the flashing light's efficacy as a warning depends on the conspicuity of a series of flashes, not on the luminance of a single flash alone. With a contrast of 1.00 millilambert, subjects will respond to a series of light flashes in a complex situation with the same speed regardless of whether the flash is once each second for 1/2 second, twice for 1/4 second, or four times a second for only 1/8 second. At low contrast, a short, fast-flashing light seems to be more conspicuous than a longer, slow-flashing signal.

In 1957, Gerathewohl found that subjects respond more quickly when the flash rates are faster, though three flickers per second was the fastest rate he used.

Cohen and Dinnerstein (1958) studied the relationship between flash frequencies and the ability to identify the various rates correctly.

Ten subjects judged nine flash rates that varied from one flash each four seconds to 12 flashes a second. The stimulus was a high-intensity blue-white Strobotron tube, masked to a point source.



They found subjects could discriminate an absolute maximum of five flash categories under the best circumstances. Even using four stimulus categories resulted in occasional confusions. The authors recommend using only three flash rates: four per second, one per second, or 20 per minute.

The study by Newman and Davis (1961), corroborates the inefficiency of flash rates as a coding dimension.

All these studies indicate that flash frequency is a poor way to present information. It is detrimental to performance under all conditions. The best possible use for this coding dimension would be as an attention-getting device with flicker rates of four per second, one per second, or 20 per minute. At low contrast, a short, fast-flashing light seems to be more conspicuous than a longer, slow-flashing signal.

### Brightness

The number of brightness steps that an observer can correctly identify depends, in part, on the range of brightnesses available. Assuming that a range from 1 to 50 millilamberts is practical, an observer can probably use not more than two or three brightness steps at best. Brightness coding is generally unsatisfactory because it causes poor contrast. The less-bright signals tend to be obscured by brighter surrounding signals. Also, uneven brightnesses are frequently distracting and fatiguing.

Thus, brightness is a display variable of limited applicability. Brightness can best be utilized with two code steps -- a high level for information of primary interest, and at a low level for that of secondary interest.

Newman and Davis (1961) found brightness levels detrimental to decoding performance.

### Line-Length Coding

In using line length to code information, one needs to know how subjects' accuracy in identifying any simple line length depends on the number of line lengths used. Conversely, the number of line lengths that can be identified correctly depends partly on the range of line lengths used. Assuming that a range of lengths from 0.1 inch to 1.0 inch (at 18 inches viewing distance) is practical for use on displays, the problem is to determine how many additional intermediate lengths can be used without confusion.

In a length-discrimination study reported in Reese et al. (1953), two dots (unfilled space) were projected on a screen. At the same time, an arbitrary scale like a meter stick was projected near the edge of the screen. Subjects were asked to estimate the distance between the dots in terms of the scale's arbitrary units. In another study a line of light (filled space) was projected, to be similarly estimated. Angle of inclination was also varied.

The main results showed that all lengths were underestimated. There was greater accuracy with short horizontal lines. However, the longest lines were estimated most accurately when vertically oriented. Sighting along a pencil, which was allowed in one experiment, increased the accuracy of estimates.

Baker and Grether (1954) reported that up to four line lengths (ranging from 0.1 inch to 1.0 inch) could be identified without error when presented singly. But with five line lengths, lines were identified incorrectly about 10 percent of the time. When there were more than five line lengths, errors of identification increased rapidly.

### Inclination Codes

Line inclination has been found to provide more categories than any other basic system when a large alphabet is required. An inclination code consists of a line extending outward from a central hub. The alphabet consists of a set of lines whose inclination is varied in discrete steps.

Rogers et al. (1947) flashed lines of light on a glass screen and asked 53 subjects to estimate the bearing in degrees. Results showed individual estimates of inclination to be considerably inaccurate. The most accurate estimates were for  $0^{\circ}$  and  $90^{\circ}$ .

~~Muller et al. (1955) give data which show that 90 percent of people can identify 24 symbols with practically no error after two or three hours of training if there is no random variation in inclination (noise) on the display.~~

The length of lines forming the symbols can be made as short as 0.1 inch. A length of 0.2 or 0.3 inch is preferable.

If a smaller alphabet is desired, or if some amount of noise is expected to degrade the symbols, the 20-, 16-, and 12-symbol alphabets are recommended (Fig. 16).

The  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$ , and  $270^{\circ}$  symbols are most quickly and accurately identified under all conditions and are included in all of the preceding alphabets; if an eight-symbol alphabet is desired, these four inclinations plus  $45^{\circ}$ ,  $135^{\circ}$ ,  $225^{\circ}$ , and  $315^{\circ}$  should be used.

The 24-category symmetric inclination code should be used only if about two percent error in performance can be tolerated. If such a degree of error is unacceptable, then another alphabet with fewer and more widely spaced symbols must be selected.


The value of using angular orientation of lines to code such information as target course depends upon:

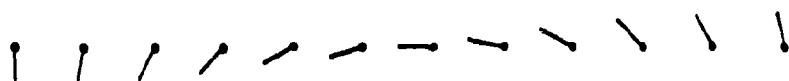
- a. Target-course accuracy requirements.
- b. Space available on the display.

Figure 17 illustrates how such a coding method could be used. The angular orientation (azimuth) of a line indicates the direction of movement, and line length is directly proportional to the target's velocity.

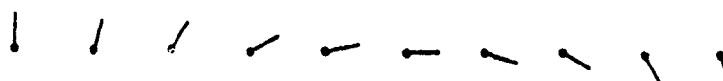
Estimating target course from line lengths leads to these errors:

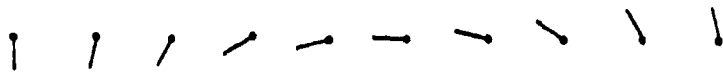
- a. Fifty percent of the course estimates will be in error by less than  $6^{\circ}$ .
- b. Ninety-five percent of the course estimates will be in error by less than  $15^{\circ}$ .
- c. These values are approximately correct for line lengths as short as 0.1 inch (visual angle of 12 minutes of arc at 28 inches viewing distance) and for untrained observers.
- d. The errors are 55 percent greater for courses from  $180^{\circ}$  to  $360^{\circ}$  than for courses from  $0^{\circ}$  to  $180^{\circ}$ . This error might be reduced if the  $180^{\circ}$  to  $360^{\circ}$  courses were expressed in minus values of  $0^{\circ}$  to  $180^{\circ}$ , e.g., a circle (split vertically) would have its left side read in minus  $0^{\circ}$  to  $180^{\circ}$  values rather than  $180^{\circ}$  to  $360^{\circ}$  values.

Symbol :   
Inclination : 0° 10° 27° 45° 63° 80° 90° 100° 117° 135° 153° 170°


Symbol :   
Inclination : 180° 190° 207° 225° 243° 260° 270° 280° 297° 315° 333° 350°

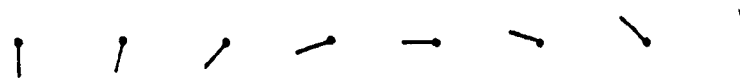
#### 24-Symbol Alphabet

Symbol :   
Inclination : 0° 12° 30° 60° 78° 90° 102° 120° 150° 168°


Symbol :   
Inclination : 180° 192° 210° 240° 258° 270° 282° 300° 330° 348°


#### 20-Symbol Alphabet

Symbol :   
Inclination : 0° 15° 45° 75° 90° 105° 135° 165°

Symbol :   
Inclination : 180° 195° 225° 255° 270° 285° 315° 345°

#### 16-Symbol Alphabet

Symbol :   
Inclination : 0° 20° 70° 90° 110° 160°

Symbol :   
Inclination : 180° 200° 250° 270° 290° 340°

#### 12-Symbol Alphabet

Fig. 16. INCLINATION CODES

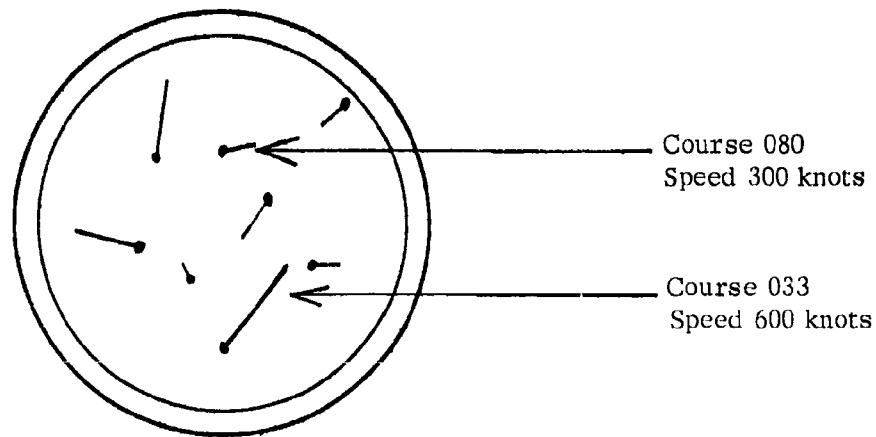


Fig. 17. DISPLAY USING CODING BY ANGULAR ORIENTATION

#### Eight-Bit Binary Code

The eight-bit binary code consists of from one to eight lines originating in a central hub. The alphabet consists of 256 unique symbols that can be produced by the presence or absence of each of eight positions of inclination:  $0^{\circ}$ ,  $45^{\circ}$ ,  $90^{\circ}$ ,  $135^{\circ}$ ,  $180^{\circ}$ ,  $225^{\circ}$ ,  $270^{\circ}$ , and  $315^{\circ}$  (Fig. 18).

Each radius is read as a single number, beginning with position one; zeros are not read. The length of radius lines should not be less than 0.1 inch. If space permits, a length of 0.2 inch is recommended.

#### Clock Code

The clock-code symbol consists of a long and a short line, each emerging from the same central hub. The alphabet consists of a set of discrete inclinations of the two lines (Fig. 19).

Read-out is in terms of clock time. It provides the easiest read-out. As an alternative the longer line can be read as A, B, C, or D, and the shorter line as 1 through 12. The ratio of the lengths of the two lines should be two to three; for read-out at a 28-inch reading distance, the shorter line should be at least 0.1 inch long.

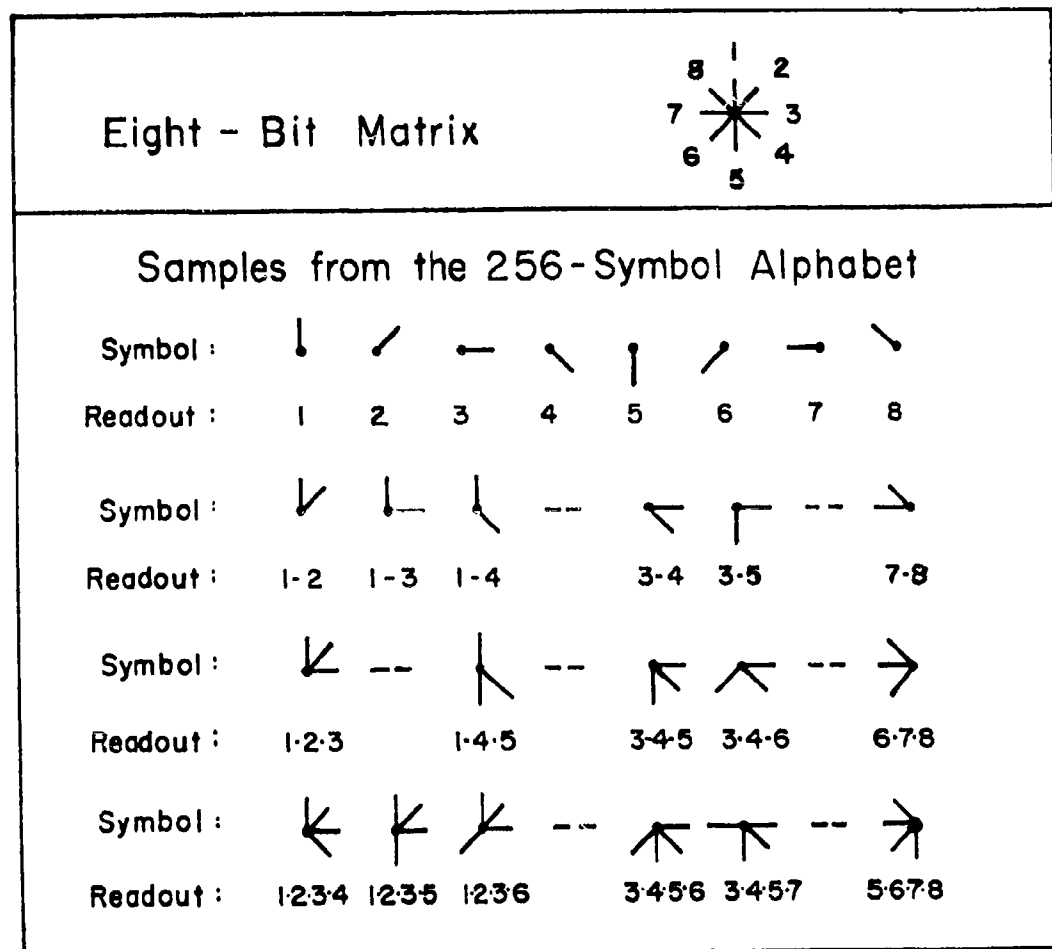


Fig. 18. EIGHT-BIT BINARY CODE

## 44-Symbol Alphabet

Symbol :								
Clock :	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00
Readout								
Symbol :								
Clock :	9:00	10:00	11:00	1:15	2:15	4:15	5:15	6:15
Readout								
Symbol :								
Clock :	7:15	8:15	9:15	10:15	11:15	12:15	1:30	2:30
Readout								
Symbol :								
Clock :	3:30	4:30	5:30	7:30	8:30	9:30	10:30	11:30
Readout								
Symbol :								
Clock :	12:30	1:45	2:45	3:45	4:45	5:45	6:45	7:45
Readout								
Symbol :								
Clock :		8:45	10:45	11:45	12:45			
Readout								

Fig. 19. CLOCK CODE

### Radius Length-Inclination Combination Code

This code symbol is a radius line extending outward from a central hub. The alphabet consists of 12 categories of inclination combined with three lengths (Fig. 20).

The recommended lengths for the three radius lines are 0.10, 0.15, and 0.30 inch. The read-out prefix number refers to the length of the radius line, while the suffix number refers to its inclination position. An alternative is using alphabetical symbols -- A, B, and C -- to refer to length of the radius line.

When Alluisi and Muller (1958) used three inclination codes (Fig. 6), numerical codes were superior.

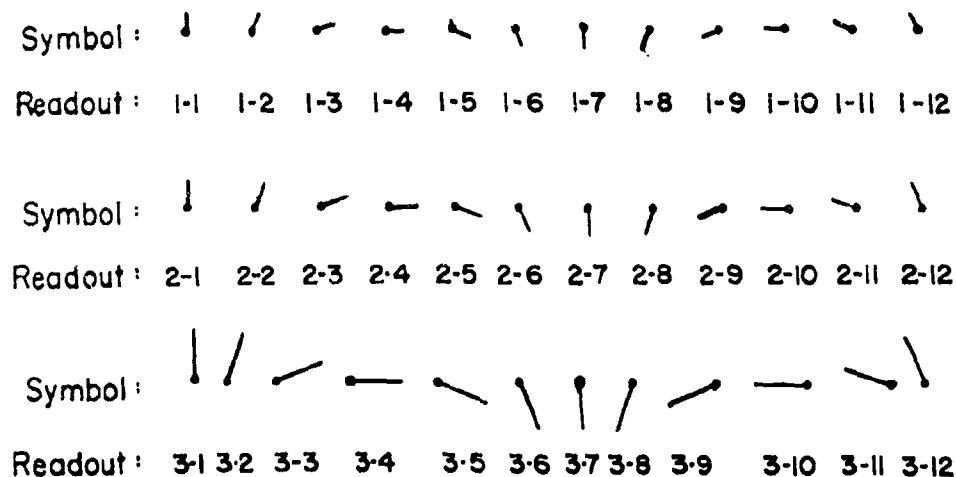


Fig. 20. RADIUS LENGTH-INCLINATION COMBINATION CODE

Learner and Alluisi (1956) measured the speed and accuracy of using four different line-inclination codes. Each scheme consisted of an alphabet and read-out for decoding the symbols into numerical representations of elevations in thousands of feet.

Each of the four systems was presented to a different group of 20 subjects. Each subject decoded 50 symbols representing elevations from 1000 - 50,000 feet in 1000-foot increments (Fig. 21).



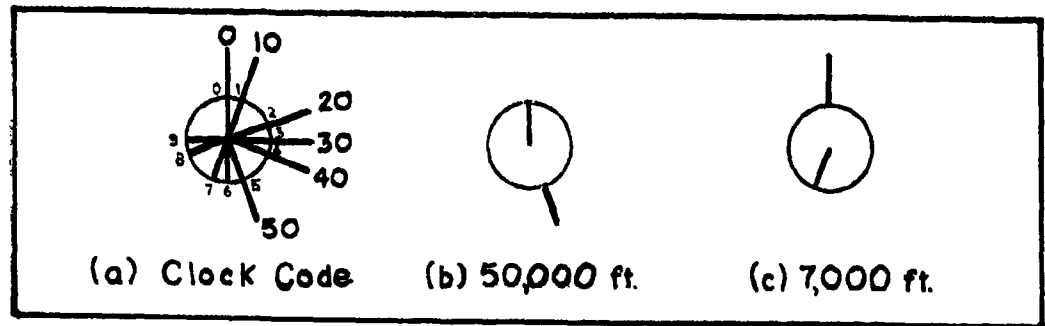
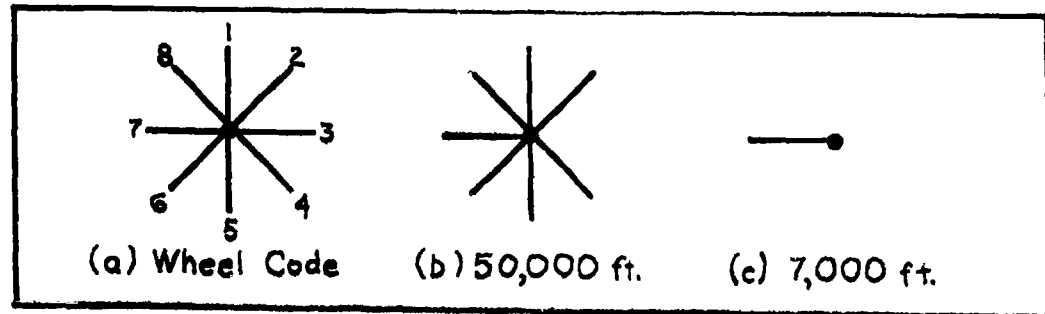
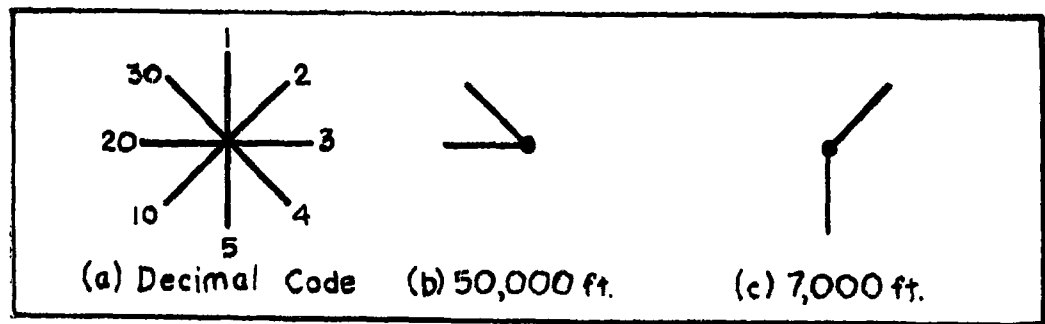
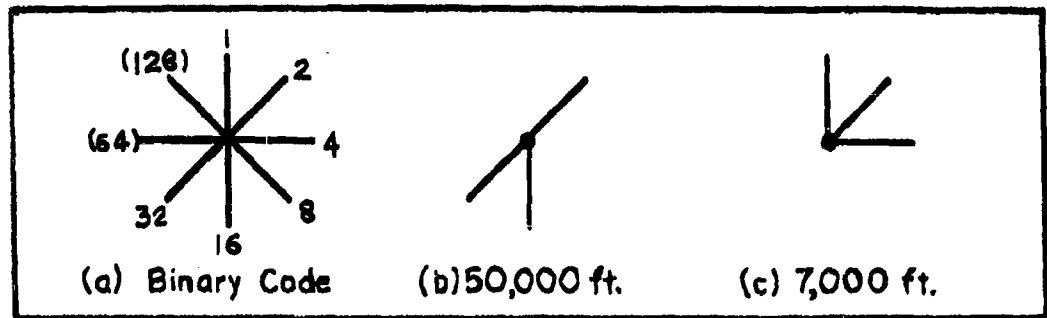


Fig. 21. BINARY, DECIMAL, WHEEL, AND CLOCK CODES

The binary code was derived from a basic symbol of ~~eight lines radiating from~~ a central hub at  $45^\circ$ -angle separations. A specific combination of displayed lines represented a specific altitude. The altitude was determined by the addition of the values assigned to each of the displayed lines. For example, when the  $45^\circ$ ,  $180^\circ$ , and  $225^\circ$  lines were present, the symbol represented an elevation of  $2 + 16 + 32 = 50,000$  feet. An alphabet of 225 symbols could be formed in this manner.

The decimal code was similar to the binary, except that the values assigned to the line positions were different. When the  $45^\circ$  and  $180^\circ$  lines were present, the symbol represented an elevation of  $2 + 5 = 7,000$  feet. Sixty-nine symbols were possible with this alphabet.

The wheel code had an alphabet of 56 symbols and elevation read-out was accomplished by some mental gymnastics. When all except the  $90^\circ$  line were displayed, the symbol represented the elevation of  $([7-1] \times 8) + 2 = 50,000$  feet.

The clock code consisted of a circle and two lines. The radius and radial extension were each positioned like the hands of a clock. When the 5 o'clock long line was displayed with the 12 o'clock short line, the symbol represented an elevation of  $50 + 0 = 50,000$  feet. There were 129 symbols in this alphabet.

Subjects were instructed in groups as to the codes, then given an instruction booklet and the symbols to be decoded. Subjects recorded their own times after each tenth symbol. Thus there were 80 timekeepers in this study.

The results showed that the decimal and clock codes were decoded with greater speed than the wheel and binary codes. The wheel code was less accurately decoded than the other three codes.

### Ellipse Codes

An outlined ellipse is the symbol for this code. The alphabet consists of a set of ellipses with the minor axis varied in discrete steps. If there is no noise on the display, a maximum of eight symbols can be identified accurately. The 0.00 and 1.00 axis ratios are identified most accurately and quickly under all conditions. The ellipse's major axis may be reoriented to carry additional information, since such rotation has no effect upon identification. The major axis may be made as small as  $1/4$  inch.

The 7-, 6-, or 5-symbol alphabet is recommended if there is noise or to make the symbol alphabet smaller (Fig. 22).

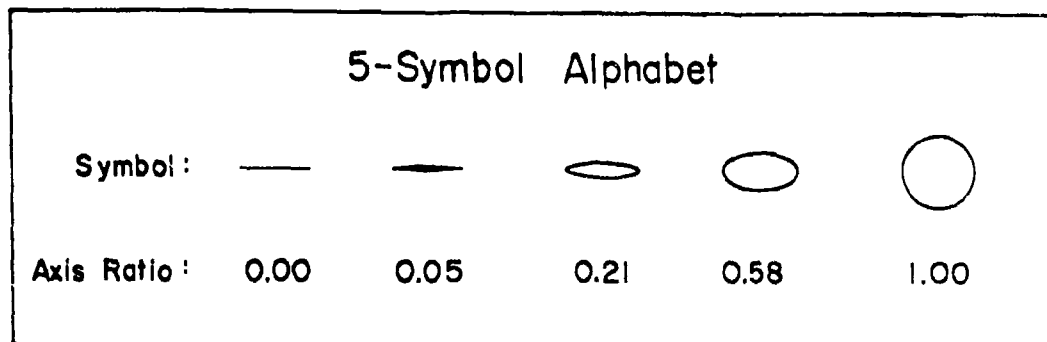
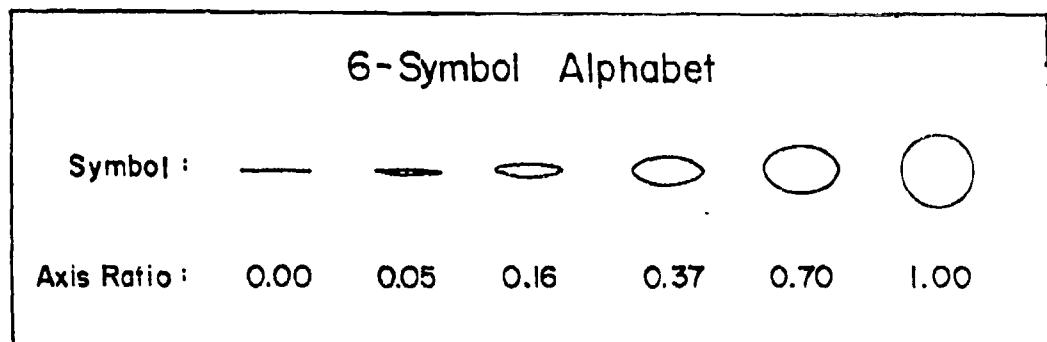
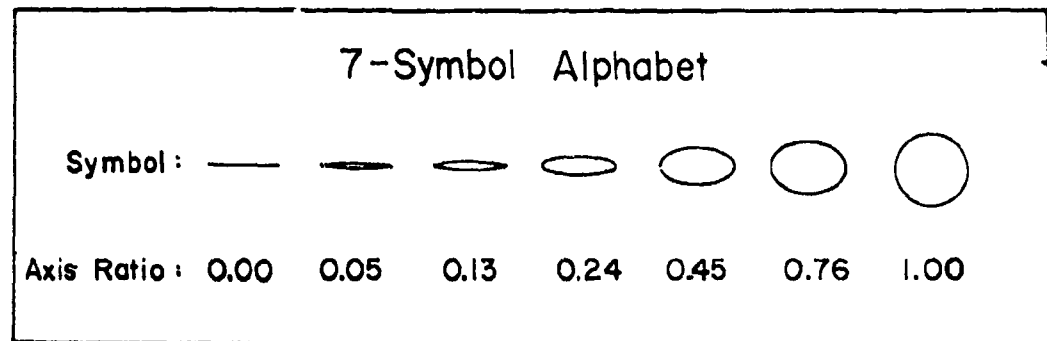
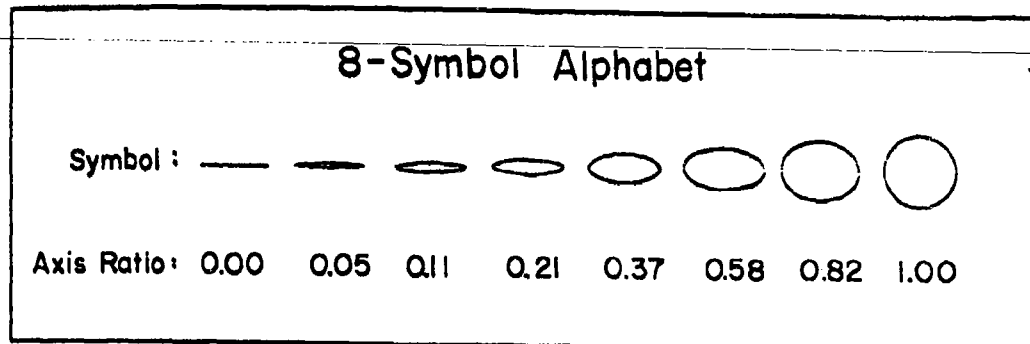


Fig. 22. ELLIPSE CODES

### Combination Ellipse-Inclination Code

The ellipse code may be combined with the inclination code, producing a symbol alphabet of six ratios with four positions of inclination. (The full circle is not used.) The major axis should not be less than 1/4 inch (Fig. 23).

Alluisi and Muller (1958) found that ellipse-axis-ratio codes were an inferior coding method.

























24-Symbol Alphabet						
Symbol :						
Readout :	A-1	A-2	A-3	A-4	A-5	A-6
Symbol :						
Readout :	B-1	B-2	B-3	B-4	B-5	B-6
Symbol :						
Readout :	C-1	C-2	C-3	C-4	C-5	C-6
Symbol :						
Readout :	D-1	D-2	D-3	D-4	D-5	D-6

Fig. 23. COMBINATION ELLIPSE-INCLINATION CODE

### Blip-Diameter Code

This code consists of a circular blip. The symbol alphabet comprises a set of blips whose diameter varies in discrete steps. If the display has no noise, subjects can identify a maximum of five symbols in the range of 0.05- to 0.30-inch diameter. Within the limited range of 1/8-inch to 1/4-inch diameter, only three symbols can be accurately identified (1/8, 3/32, and 1/4 inch). If a smaller symbol alphabet is desired, the four-symbol or three-symbol code is recommended (Fig. 24).






The recommended read-out numbers the symbols serially, beginning with the smallest-diameter symbol as number 1.





For the average observer, the equivalent of only five blip categories was absolutely recognizable. Probably all people could discriminate only three or four categories. However, this limited number of categories seriously limits the symbol's usefulness as a primary code.

### Visual-Number Coding

A target can be coded by correlating some dimension of information with the number of dots comprising the target signal. For example, a one-dot signal would represent a target value that is different from a two- or three-dot signal. In 1924, Oberly did a study exposing dots for less than 1/10 of a second so that observers were unable to count but had to estimate the number of dots exposed. He found that errors are negligible for identification of signals coded by five dots or less; above six dots, errors rise rapidly. These accuracies are for immediately identifying the number of dots. If more time were allowed for observation, the accuracy would be greater. But the time required for identification is usually critical. If immediate identification is required, it appears that as many as five or six coding steps could be used to code signals.

Kaufman et al. (1949) arrived at much the same conclusions. They were interested in how subjects estimate numbers without counting. They showed nine subjects fields of dots and asked them to report the number. The field was exposed 1/5 second; there were 35 different fields ranging from 1 to 210 dots. Each field was presented 20 times. The results indicate that people handle numbers up to six differently from numbers above six. There was extreme accuracy and consistency up to six dots. Beyond six, both accuracy and consistency tended to decrease. Report time increased up to six dots, then remained constant. The subjects' confidence in their estimates was maximum up to six, then dropped sharply and leveled off.

5-Symbol Alphabet					
Symbol :					
Diameter : in inches	.05	.07	.12	.21	.30

4-Symbol Alphabet				
Symbol :				
Diameter : in inches	.05	.10	.18	.30




3-Symbol Alphabet			
Symbol :			
Diameter : in inches	.05	.12	.30

Fig. 24. BLIP-DIAMETER CODES

The main conclusion is that, if there are not more than six things to be seen, we can depend upon what the observer tells. Accuracy and consistency decrease with more than six dots, but the average error is small up to 25 dots. Training might increase accuracy to the point where one could rely on reports up to 25 dots for many practical purposes.

Similar results were found by Graham (1952), who used from 1 to 757 dots. Subjects estimate small numbers of dots adequately in a relatively short time, and with high confidence. Larger numbers of dots -- 6 to 12 -- are overestimated; numbers of dots above 13 are underestimated.

Jensen et al. (1950) found that the best method of counting dots was by twos; the next best, by ones. Counting by threes, fours, fives, or by any other way, is slow and inaccurate. When counting by ones, people overestimate. When counting by twos through fives, they underestimate.

#### Stereo-Depth Coding

Stereoscopic depth has been considered as a method of coding information. Stereoscopic depth results from binocular disparity, i.e., a slightly different picture is given to each eye. When the degree of disparity is not very great, the images fuse; that is, they are seen as one. It is fusion of these disparate images that produces stereoscopic depth perception. The range and azimuth of a target are displayed as on the conventional PPI, but its altitude (or any other dimension) is coded by the apparent depth of the target.

The primary problem with three-dimensional displays concerns the observer. The operator must have normal three-dimensional vision to use this type of display effectively. Unfortunately, estimates suggest that between 10 and 60 percent of the population have deficient depth vision. In addition to poor depth vision caused by poor vision in one eye, muscular imbalance, or image suppression, three-dimensional vision could break down when fatigue degrades muscular balance, resulting in loss of fusion during long periods of observation.

At this time stereo-depth coding has not been developed sufficiently technologically for use under field conditions. Thus stereo depth remains a poor coding dimension.

## Combination Codes

A target is simply coded if it carries only one code. Such a target might be colored, flickered, or shaped, but it would never have more than one of these dimensions at a time. Simple coding reduces problems of comprehension and interpretation to a minimum. However, it also reduces the amount of information carried by the target.

A target which is colored, flickered, and shaped is an example of a compound code. There is no doubt that compound codes degrade speed and accuracy of code reading, probably in exponential ratio as the number of codes is increased. But, by using compound codes, more dimensions of information may be put into a display.

When only one dimension is to be coded (such as friend vs. foe), it should be coded by one code dimension. If two or more dimensions are to be coded (friend vs. foe and bomber vs. fighter), there should be two coding dimensions. It would not be wise to use one coding dimension to code two dimensions of information. For example, do not use color to code all this information: red - enemy bomber, yellow - enemy fighter, green - friendly bomber, blue - friendly fighter. Preferably, use color for friend (green) and foe (red), and shapes for bomber (cross) and fighter (circle). This method of coding makes it easier to interpret the information displayed.

One system now used in aircraft has a large alphabet of compound codes, with 64 different symbols (Ref. 2). A similar system used at sea has approximately 52 different symbols. If combined with a similar ground-base system, there are 5,082 possible combinations.

The basic symbol designs and their meanings are identical in all three systems.










<u>BASIC SYMBOLS</u>			
<u>GENERAL</u>	<u>FRIENDLY</u>	<u>UNKNOWN</u>	<u>HOSTILE</u>
Air			
Surface			
Sub-Surface			

Fig. 25. BASIC SYMBOL DESIGNS



Newman and Davis (1961) examined whether, when a constant amount of information is displayed, it is advantageous to reduce the number of symbols by substituting other coding dimensions such as brightness, color, and flashing. The study evaluated whether symbol-only coding or symbol-plus-other-dimension coding was faster and more accurate for reading coded information.

They studied 36 geometric symbols, two brightness levels, three flashing rates, and three colors (red, yellow, and green) (Fig. 26). Ten Navy men were trained exhaustively, then tested in using the vocabulary to decode.

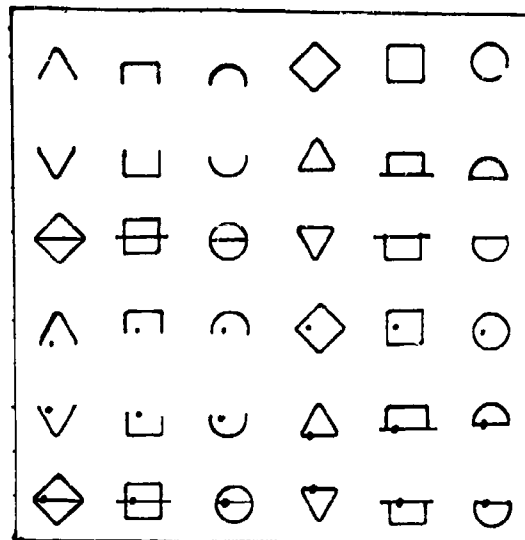


Fig. 26. FORMS USED BY NEWMAN AND DAVIS (1961)

During the first part of the experiment, the subject searched a matrix to locate the one symbol which matched a sample stimulus in geometric shape, color, brightness, and flash rate.

In the second part, the subjects had to decode symbols located at specific coordinates on the display. Parts three and four involved finding and decoding two overlapping symbols in each of 18 randomly determined cells on the matrix.

The results indicated that symbol-plus-color coding is easier to locate and decode. Errors were most frequent in conditions with a relatively large number of coding variables. The complexity of the 36 different geometric-symbol variations led to long response times; the three flashing rates caused perceptual confusion and uncertainty in the localizing tasks. For decoding tasks, color was significantly superior. The 36 symbol shapes did not cause much difficulty in decoding.

The three flash rates, alone or in conjunction with brightness levels, should not be used for coding in any task, the experimenters assert.

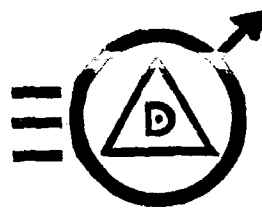
Except with geometric shapes, combining two or three levels of coding dimension in one condition degrades performance, particularly when the combination includes three different flash rates. The findings also emphasize the distinction between perceptual and learning-recall tasks, and point out the necessity for carefully selecting and thoroughly training personnel for the tasks they must perform in handling coded data on visual displays.

Bowen et al. (1959) recommended the following rules for building combination codes:

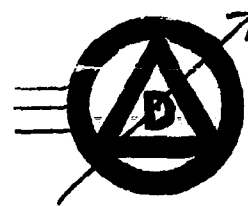
- a. Primary symbols should be large and enclose a space.
- b. No auxiliary symbol should cross, distort, interfere with, or in any way obscure the primary symbol.
- c. Symbol complexes should not normally exceed two geometric symbols, or possibly three in some circumstances: a location dot, and a speed and direction vector line where applicable.
- d. When other information is required, it should be represented numerically (e.g., one, two, or three marks to indicate magnitude of object) or in actual numbers and letters.
- e. The geometric center of the symbol and/or a large clear dot should indicate location.
- f. Auxiliary marks should be compact solid figures.

Figure 27 illustrates good and bad practice in constructing combination codes.

Combination codes lose their advantages and efficiency quickly if too much information is portrayed. Hence, information should be kept to essentials. An effective device for avoiding too-large quantities of information is presenting different categories of information on a selective, "on-demand" basis. Here the operator decides what specific information he needs and is then able to elicit this information at will.



Good



Bad

Fig. 27. GOOD AND BAD PRACTICE IN COMBINATION-CODE CONSTRUCTION

## SYMBOL MEANING

Surveying existent symbol codes shows that there are few consistent symbol meanings. In military applications, straight-line angular forms generally indicate hostile vehicles, while rounded forms usually indicate friendly vehicles. Crossed lines often indicate a fixed or reference point.

Torre and Sanders (1958) had 100 enlisted men invent symbols (no numbers or letters) for the terms "friendly," "unknown," and "enemy." The symbols elicited were categorized into one or more of eight classifications.

The authors asserted that enemy-target meaning elicited symbols characterized by open form and straight lines such as X; that friendly-target meaning elicited symbols of closed forms like stars; and unknown-target meaning was characterized by curved-line forms such as question marks. These types of forms were the basis for a second experiment. Here, 36 subjects labelled eight groups of two or three symbols as "enemy," "friendly," "unknown." The results indicate that the most stable preferences were  $\oplus$  for the enemy symbol (gun-sights are associated with hostility), and stars associated with friendly symbols (stars for friendly insignias representing the United States). The question-mark symbol was associated with a question or something unknown.

Certain symbols have readily apparent meanings based largely on common usage:

- a. An arrow points in the direction of travel.
- b. Size or numerosity indicates magnitude.
- c. Red stands for danger or emergency.
- d. A flickering symbol indicates emergency.
- e. Location is at the geometric center of the symbol or at a dot.

Symbol codes should comply with these major-meaning associations. In addition, whatever meanings are associated with symbols should be standardized if possible. Designers should verify that the associations do not contradict "natural" associations.

## RECOMMENDATIONS

### GENERAL RECOMMENDATIONS

The basic principles for selecting a symbolic code are:

a. Number of Categories

There must be a finite number of discrete symbols to provide information in symbolic form. The minimum number of categories required for a specific application must be determined first.

b. Minimum Information

A symbol type and an alphabet should be selected, in which a single meaning is attached to the symbol.

c. Absolute Identification

Observers must be able to read code symbols without referring to comparison standards. This type of read-out requires absolute recognition, in contrast to relative discrimination.

d. Safety Factors

If noise is expected to affect the display (i.e., random variation in the symbol strength), a safety factor must be introduced, and the alphabet must use less than the maximum number of discriminable categories.

e. Combination Codes

If more information must be displayed than any one type of coding symbol allows, or if more than one type of information is to be provided by a single symbol, then one of the combination codes may be used. The respective symbols must be capable of being read out separately without confusion.

f. Ease of Learning

The code system must be one users can learn easily, and its interpretation should not be affected by emergencies or adverse conditions.

g. Symbol-Read-Out Compatibility

The symbol and the event it symbolizes should have a natural relation. Their association should conform to well-established habits or population stereotypes.

h. Optimum Size

Symbols should be large enough for good legibility, yet small enough to fit on a screen without clutter or interference with read-out of other information.

i. Technical Feasibility

It must be technically feasible (i.e., within the "state of the art") to generate the symbols.

j. Symbol Spacing

Symbols should be spaced for easiest and fastest read-out.

## SPECIFIC RECOMMENDATIONS

### Numerals and Letters

1. Alpha-numerics should subtend a visual angle of at least five minutes (1/40-inch-high symbols read at a 15-inch viewing distance). For other viewing distances, multiply the viewing distance in inches by .0017 and round to three numbers to determine optimum symbol size.
2. Symbols should be oriented to appear in an upright position.
3. Symbols should be about 0.5-inch high and have a stroke-width 1/8 to 1/10 of the height. If smaller symbols must be used, the stroke-width-to-height ratio must be 1:10 or less. Stroke-width must be at least 0.02 inch, but no more than 0.14 inch.
4. Standard numerals (MIL-M-18012) should be used.
5. Of all symbolic numerals, those derived from an eight-element straight-line matrix are read most easily.
6. Standard letters (MS 33558) should be used.
7. Lower-case letters are confused more readily than upper-case; upper-case should be used.
8. Confusing letter combinations -- t and l, v and w, c and o, and m and n -- should be avoided.
9. Confusing letter-number pairs -- Q and 0, 1 and I, 8 and B, 2 and Z, and 5 and S -- should also be avoided.

### Geometrics

1. The circle, rectangle, cross, and triangle are the most distinctive geometric forms.
2. Squares, polygons, and ellipses are discriminated poorly; they should be avoided.
3. Variations of a single geometric form -- such as sets of round, pointed, or triangular characters -- should be avoided.

4. Unique symbols (e.g., swastika, anchor, flag, rocket, airplane) are good in specific situations.

5. Symbols should be few in number and under adverse display conditions should not exceed six.

6. Stroke-width-to-height ratios of 1:8 to 1:10, and symbols 0.4 inch or larger, are best for viewing up to seven feet.

7. Symbol meanings should be compatible with their conventional, stereotyped meanings.

#### Color

1. Color presents excellent possibilities for an easily discriminable code, but the difficulty in generating discriminable color signals precludes its use in many CRT displays at this time.

2. When color generation is improved, colors can be used best in combination with alpha-numerics or geometrics.

#### Flicker

1. Flicker is excellent for attracting attention; it should be reserved for use in emergency situations only.

2. Three flicker rates should be the maximum in any practical situation. These rates, assuming a 50 percent on-off ratio, are four flashes per second, one per second, or one every three seconds.

3. Flicker is tiring and annoying to watch; thus it is an undesirable coding dimension.

#### Brightness

1. It is difficult to discriminate more than two brightness levels (high and low).



### Line Length

1. Four line lengths, ranging from 0.1 inch to 1.0 inch, can be identified without error.

### Inclination

1. Many variations are possible in combination with other codes.
2. Training is necessary for accuracy.
3.  $0^{\circ}$ ,  $90^{\circ}$ ,  $180^{\circ}$ , and  $270^{\circ}$  are identified most accurately.  $45^{\circ}$ ,  $135^{\circ}$ ,  $225^{\circ}$ , and  $315^{\circ}$  may be used if a larger alphabet is required.
4. Line length should be between 0.2 and 0.3 inch.

### Ellipse

1. Ellipses are a poor coding dimension.
2. Three ellipse sizes -- 0.11, 0.45, and 0.82 inch -- are most practical for display purposes, where ellipses only are displayed.

### Blip Diameter

1. No more than three blip sizes (i.e., .05, .12, and .30 inch) should be used in radar displays.

### Visual Number Coding

1. Using this dimension for coding is detrimental to performance.
2. No more than six dots can be used in a practical situation.

### Stereo-Depth Coding

1. Technologically, this dimension has not developed sufficiently for use.

### Combination Coding

1. No more than two symbols should be combined where symbols must be used rapidly and accurately.
2. No auxiliary symbol should cross, distort, interfere with or in any way obscure the primary symbol.
3. When other information is required, it should be represented numerically or in actual numbers or letters.
4. The geometric center of the symbol and/or a large clear dot should indicate location.

### Symbol Meanings

Limited research has indicated that certain code symbols have stereotyped meanings and should be used with those meanings.

1. Straight-line, angular forms generally indicate hostile vehicles.
2. Rounded forms generally indicate friendly vehicles.
3. Crossed lines are generally used to indicate a fixed or reference point.
4. An arrow points in the direction of travel.
5. Size or numerosity indicates magnitude.
6. Red stands for danger or emergency.
7. A flickering symbol indicates emergency.
8. Location is at the geometric center of the symbol or at a dot.

Much of the literature in the field of radar symbology has been brought together by this review. The fact that there has not been sufficient work done in choosing one code system, assigning meaning, and evaluating it, has been highlighted. Few studies employed actual radar scopes in their experimental designs. Stimuli were presented to subjects on projectors, viewers, slides, and tachistoscopes. While, in some cases, these methods are analogous to radar-scope presentation, the results gleaned from study with one kind of apparatus are not completely applicable to another. Few studies varied conditions such as temperature, humidity, air pressure, stress, or acceleration as they might vary in the field. Before confidently recommending one specific code system over another, it would be necessary to evaluate both experimentally in situations similar to field conditions. While it has been possible to make definitive recommendations about code characteristics, establishing any standard symbology must await further research.

Before a standard symbology for all radar detection systems can be established, the following problems remain to be explored:

- a. What informational display methods can an operator best use?
- b. Do we really need a symbol system to display information to an operator, or are other techniques better?
- c. What is the minimum information an operator needs to make a decision in a given situation; what is the maximum amount of information an operator can handle to make decisions?
- d. What decisions should be left to an operator?
- e. What is the optimum division of operator work loads in systems where operators must interact?
- f. Are there population symbol stereotypes, and if so, what are they?
- g. If color is used as a coding dimension, what exact wavelengths should be specified?

There is need for a study comparing all symbols judged best in all studies to resolve the confusing results found when symbols judged best in one study are not compared with symbols judged best in a second study.

The selection of symbols for a standardized symbology should most certainly be based upon carefully controlled research.

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# APPENDIX A

Summary Table of Coding Methods  
(Adapted from Baker & Grether, Ref. 12)

Code	Number of Steps in Code	Evaluation	Comments
Alpha-numerics	Unlimited	Excellent	High information-handling rate. Unlimited number of coding steps.
Geometrics	20 or more	Excellent	Certain shapes easily recognized. Many coding steps.
Color	4	Excellent	Difficulty in techniques of reproducing for cathode-ray tubes. Objects quickly and easily identified.
Flicker	5	Poor	Distracting and fatiguing. Interacts poorly with other codes. Best for attracting attention. Few steps in code.
Brightness	3	Poor	Limited number of steps. Fatiguing. Detrimental to decoding performance.
Line Length	4 - 5	Fair	Limited number of steps. Will clutter display.
Angular Orientation	12	Fair	95% of estimates will be in error less than 15°.
Inclination	24 or more	Fair	Many coding steps, especially with combinations.
Ellipse	7 or fewer	Poor	Few steps. Poor for information handling.
Slip Diameter	5 or fewer	Poor	Few steps. Noise on display interferes.
Visual Number	6	Fair	Few steps.
Stereo-Depth	?	Fair	Requires complex display. Many people cannot use because of faulty vision.
Combinations	Unlimited	Good	Care must be used to prevent overloading symbols with too much information. Detrimental to quick performance.

## APPENDIX B

### Minimum Satisfactory Sizes for Visual Elements (From Bowen et al., Ref. 23)

Element	Dimension	Viewing Conditions <sup>a</sup>		
		Good	Average	Poor
Spots and circles	Diameter	0.02"	0.06"	0.30"
Squares	Length of side			
Rectangles	Length of shorter side			
Lines	Width	0.005" (for bright line on dark background) 0.01" (for dark line on bright background)	0.02" (recommended as minimum for radar use)	0.05"

<sup>a</sup>Definition of viewing conditions:

Good -- Brightness high (10 or more millilamberts);  
Brightness contrast high (90% or more);  
Viewing distance short (not more than three feet).

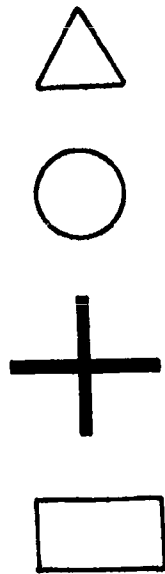
Average -- Intermediate between good and poor conditions.

Poor -- Brightness low (five or less millilamberts);  
Brightness contrast poor (50% or less);  
Viewing distance long (up to 20 feet).

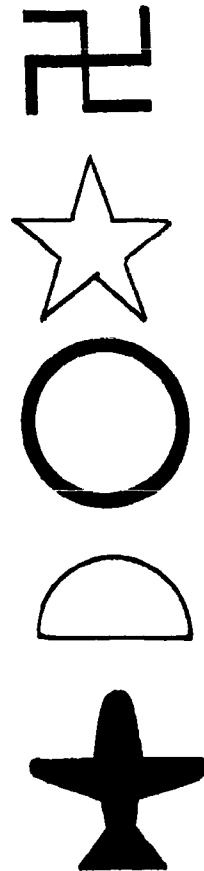
# APPENDIX C

## Rank Orders of Geometric Symbols Studied

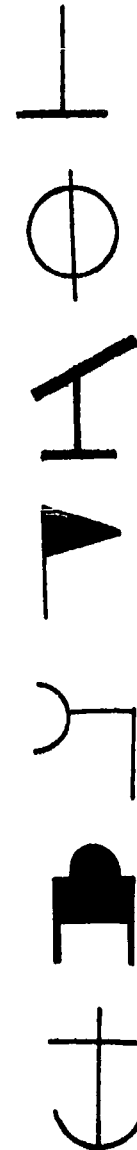
Highest ranking  
symbols used in  
four or more  
studies



Highest ranking  
symbols used in  
fewer than four  
studies



Symbols used  
deserving more  
intensive study












# APPENDIX D

## Summary Table of Studies Reviewed

Code	Author	Study	Results
<u>Alpha - numerics</u>			
Numerals	Dunlap, 1932	Improving legibility of license plate numerals.	Recommended light background with dark numerals, slender strokes, good spacing.
	Berger, 1943	Improving numeral legibility.	Found 2, 0, 7, 3, 5, 6, 4, 8 recognizable in that order.
	Green et al., 1953	Search time for numerals as function of other numerals on display.	Shorter search time with lesser numeral density, upright orientation.
	Cohen & Webb, 1954	Analyzed six numerical systems for visual displays.	Arabic numerals read fastest. Six-line matrix numerals read fastest of symbolic codes.
	Lansdell, 1954	Comparisons of digit systems: Mound, Mackworth, eight-line matrix.	Lansdell (eight-line matrix) numerals best.
	Alluisi, 1955	Selecting best set of matrix figures.	See Figure 4.
	Foley, 1956	Comparison of digit systems: establish confusion errors.	Lansdell figures most legible.
	Harris et al., 1956	Comparison of digit systems.	Developed Lincoln design numerals.
	Alluisi & Martin, 1957	Information handling with conventional and matrix numerals.	MS 33558 numerals most satisfactory.
	Alluisi & Muller, 1958	Information handling with conventional and six other symbolic codes.	Best verbal responses with numerical codes.
	Soars, 1958	Confusion of numbers.	Boldness of stroke and openness of white space within figure most important variables.
	Klemmer & Loftus, 1958	Discrimination of numerals vs. non-sense forms.	Symmetrical figures and continuous patterns seen better than broken ones.

# Appendix D - Continued

Code	Author	Study	Results
Letters	Roethlein, 1912	Legibility of letters.	See Table 1.
	Tinker, 1928	Legibility of letters.	See Tables 1 and 2.
	Long & Reid, 1951	Three studies: legibility of dot-formed letters.	Legibility enhanced by use of larger matrix and printing in "gray scale." Words better than letter jumbles.
	Brown, 1953; Baker & Grether, 1954	Development of standard alphabet for military equipment.	See Figure 9.
	Hodge, 1962	Legibility of letters.	See page 23.
-----			
Geometrics	Helson & Fehrer, 1932	Identifiability of different letters.	Rectangle most perceptible, then triangle, then circle.
	Hochberg et al., 1946	Identifiability of different forms.	Circle most perceptible, then square, then cross.
	Casperson, 1950	Discrimination of different forms.	Gestalt principle of "simplicity" inadequate. Triangle, cross, and rectangle best.
	Sleight, 1952	Discrimination of geometric forms.	Swastika, circle, crescent, airplane, cross, and star sorted quickest.
	Gerathewohl & Rubinstein, 1953	Discriminability of 	 -- high discriminability  -- low discriminability
	Gerathewohl, 1953	Discriminability of  under noise conditions.	 -- highest  -- next  -- lowest
	Leonard & Pitts, 1955	Perception under noise conditions.	Repeated looks at noise-distorted figures benefit performance.
	Harris et al., 1956	Comparison of geometric forms for special CRT.	Elongated symbols have excellent legibility
	Blair, 1957	Evaluation of AAOC symbols.	Rank-ordered sets of symbols.
	Dardano & Donley, 1958	Discriminability of AAOC symbols.	  most discriminable.

# Appendix D - Continued

Code	Author	Study	Results
Geometrics (continued)	Dardano & Stephens, 1958	Discriminability of AAOC symbols under field conditions.	+ ○ most discriminable.
	Bowen et al., 1959	Discrimination of 20 geometric forms.	See Figure 14.
	Fried, 1959	Discriminability of AAOC symbols under jamming conditions.	+ best under jamming.
	Coules et al., 1960	Discriminability of polygons under noise.	Polygons poor choice for visual displays.
-----			
Color	Eriksen, 1952	Speed in locating objects of different hue, form, size, and brightness.	Hue differences present shortest locating time.
	Cohen & Sanders, 1953	Reducing errors in locating dials.	Color coding provides better time than shape coding.
	Muller et al., 1955	Development of 10-symbol color alphabet.	See Table 5.
	Muller, 1955	Efficiency in handling information coded by color and light.	Performance with 10 lights superior to 10 colors. Verbal and motor responses equal with color.
	Anderson & Fitts, 1958	Information handling with different symbols including color.	Color-numerics superior to color or shape alone.
	Alluisi & Muller, 1958	Information handling with seven different codes.	Ten-color code inferior to numerical code.
	Conover & Kraft, 1959	Information handling with color and shape.	Color and shape combined are better than color or numerals separately.
	Hitt, 1961	Searching & recognizing five different coding methods.	Numeral coding best, then color.
	Newman & Davis, 1961	Reducing symbol number by substituting other coding dimensions.	Symbol plus color coding good for localizing and decoding tasks.
	Smith, 1962	Color coding in visual search.	When color is known, search time is shorter.

Appendix D - Continued

Code	Author	Study	Results
Color (continued)	Smith, 1963	Color and legibility of overprinted symbols.	Color more influential than shape in legibility of overprinted symbols.
	Smith & Thomas, 1964	Color vs. shape coding.	Counting faster with colors. Yellow, red, white most legible. Ship, missile, star forms most discernible.
-----			
Flicker	Gebhard, 1948	Scaling flicker for code.	One-half flash to 30 flashes per second possible. Fifteen discriminable steps.
	Gerathewohl, 1951, 1952, 1953, 1957	Reaction time to flashing lights.	Reaction to high flash quickest (3 fps highest rate used).
	Cohen & Dinnerstein, 1958	Identifying flash-frequency rates.	Flash frequency poor coding dimension. Five categories can be discriminated without error.
	Newman & Davis, 1961	Reducing symbol number by substituting other coding dimensions.	Flash rates are poor coding dimensions.
-----			
Brightness	Newman & Davis, 1961	Reducing symbol number by substituting other coding dimensions.	Brightness levels detrimental to decoding performance.
-----			
Line Length	Baker & Grether, 1954	Identifying line lengths.	Four different line lengths can be identified without error.
	Reese et al., 1953	Discriminations of length.	Lengths tend to be underestimated in size. Sighting along object aids accuracy.
	Baker & Grether, 1954	Estimating target course by line angle.	Fifty percent of estimates will be in error less than 6°. Ninety-five percent of estimates will be in error less than 15°.
-----			

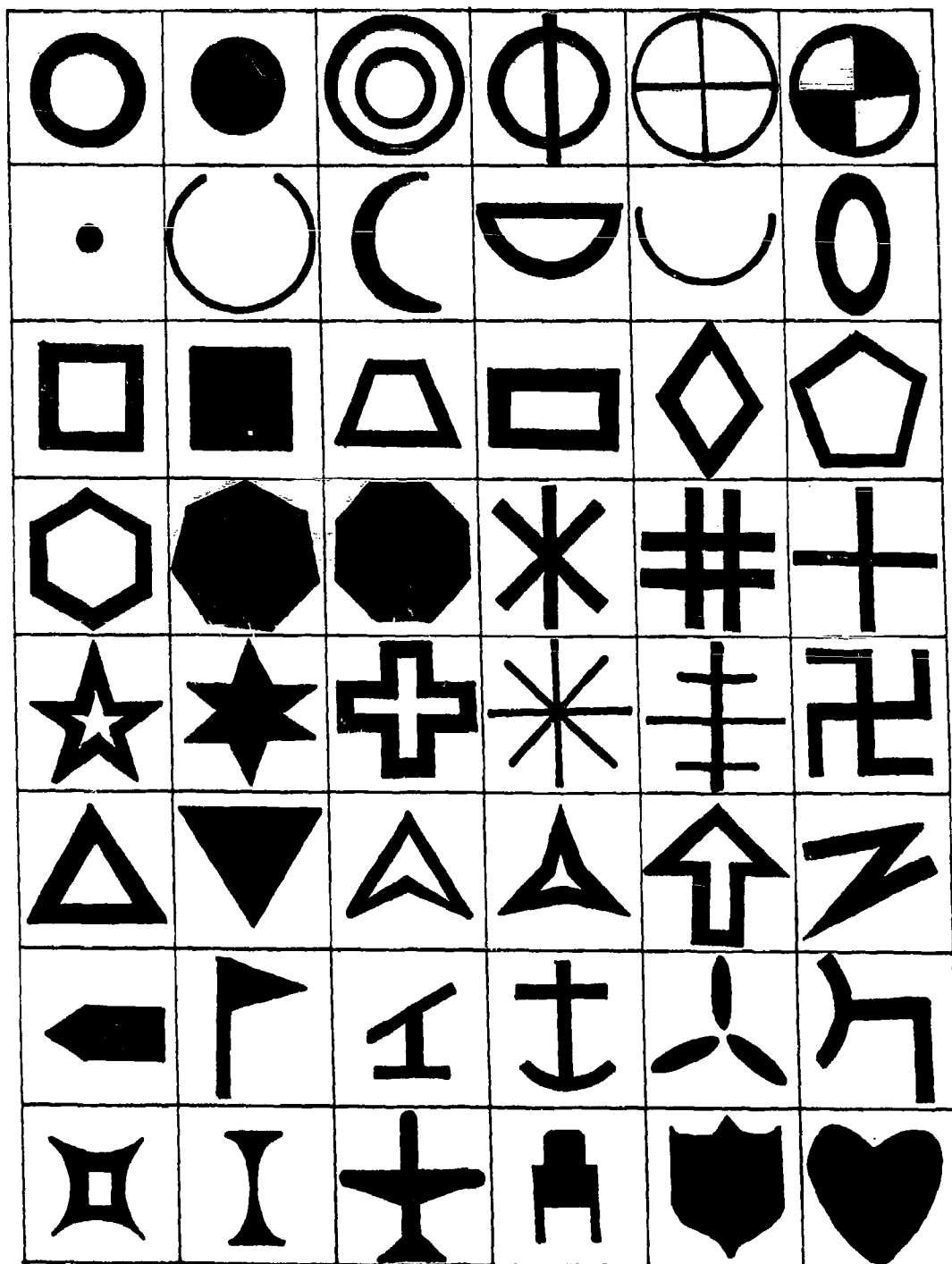
Appendix D - Continued

Code	Author	Study	Results
Inclination Codes	Rogers et al., 1953	Discrimination of line inclination.	Inaccurate estimates tend to be made.
(Eight Bit Binary, Clock, Radius Length-Inclination, Decimal, Wheel)	Muller et al., 1955	Identification of line inclination codes.	Inclinations of 0°, 90°, 180°, and 270° or straight lines most accurately identified.
	Muller et al., 1955	Identification of codes.	Twenty-four symbols can be identified after 2 - 3 hours training with 2% error.
	Alluisi & Muller, 1958	Information handling with seven symbolic codes.	Numerical codes superior to inclination codes.
	Learner & Alluisi, 1956	Information handling with four-line inclination codes.	Decimal and clock codes handled quicker than wheel and binary codes.
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<u>Ellipse</u>			
Combination Ellipse Inclination	Alluisi & Muller, 1958	Information handling with seven symbolic codes.	Ellipse codes inferior.
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Blip Diameter	See page 59.		
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Visual Number	Oberly, 1924	Estimating number of dots.	Few errors with five dots or less.
	Kaufman et al., 1949	Estimating number of dots.	Few errors with five dots or less.
	Graham, 1952	Estimating number of objects.	Six or fewer objects perceived with few errors.
	Jensen, 1950	Best method of counting dots.	Counting by twos best.
-----			
Stereo Depth	See page 61.		
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Combination	Newman & Davis, 1961	Reducing symbol number by combining coding dimensions.	Symbol plus color good. Two or three dimensions combined detrimental to performance.
	Bowen et al., 1959	See page 62.	



# APPENDIX E

## Geometric Symbols Used in Studies Reviewed



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